Environment Canterbury Regional Council
Kaunihera Taiao ki Waitaha

TECHNICAL REPORT Science Group

The current state of groundwater quality in the Orari-Temuka-Opihi-Pareora area

Report No. R18/10
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Environment Canterbury Regional Council
Kaunihera Taiao ki Waitaha

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Summary

Background:
The Orari, Temuka, Opihi and Pareora (OTOP) zone committee and Environment Canterbury are working together to set water quality and quantity limits as part of the Canterbury Water Management Strategy (CWMS). The parties aim to develop solutions for water and land management.

What we did:
We summarise the current knowledge of groundwater chemistry within the OTOP area and make interpretations based on published reports and existing data. We also highlight areas where groundwater quality is not suitable for certain uses or where groundwater quality may impact groundwater-fed surface waters.

What we found:
As the largest land use, agriculture is the largest source of diffuse contamination. There are also significant point sources of contaminants that have resulted in contamination plumes in groundwater. The largest of these discharges is from the dairy factory at Clandeboye, with other discharges occurring from the meat processing plant at Pareora and the fertiliser storage facility at Seadown. Smaller point sources of groundwater contamination include landfills and wastewater systems, including septic tanks. Contamination is most evident in shallow groundwater, but there is evidence of contamination in deep groundwater.

Soil can influence the leaching rate of contaminants. In the OTOP zone, coastal and flat areas have soils with greater potential to leach contaminants. Soils in the Downlands commonly have a fragipan that prevents significant leaching to groundwater. Poorly drained soils, such as those in the Orari and Geraldine areas, facilitate anoxic conditions which can reduce nitrate-N concentrations in groundwater. Typically, deep groundwater has less dissolved oxygen than shallow groundwater, meaning more potential for anoxic conditions.

Nitrate-N concentrations in groundwater of the OTOP zone commonly exceed the Maximum Acceptable Value (MAV) of 11.3 mg/L set by the New Zealand Drinking-Water Standards. Several recorded concentrations exceed 20 mg/L. Elevated nitrate-N concentrations in groundwater coincide with areas of intensive land use, and/or where land surface recharge is the predominant source of groundwater recharge. Exceedances of the MAV are also caused by significant point source discharges. Nitrate-N concentrations in groundwater can be constrained by factors including poorly drained soils, low dissolved oxygen concentrations, and by river water being the predominant source of groundwater recharge. Most Environment Canterbury monitoring wells do not show any long-term trend for nitrate concentrations. However, increasing trends occur in a handful of shallow wells across the zone and deep wells in Rangitata-Orton and Levels Plain. Decreasing nitrate-N trends are largely attributable to dilution from Rangitata South Irrigation Scheme.

Deep groundwater has natural concentrations of dissolved reactive phosphorus attributable to age and geology. Detections of dissolved reactive phosphorus in shallow groundwater typically coincide with elevated nitrate-N concentrations and detectable *E. coli*, suggesting land use impacts.

Of the wells with data, 58% of shallow wells and 22% of deep wells have had *E. coli* detections, suggesting widespread faecal contamination of groundwater.

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1 Introduction

The Orari, Temuka, Opihi and Pareora (OTOP) zone committee and the Canterbury Regional Council (Environment Canterbury) are working together to set water quality and quantity limits as part of the Canterbury Water Management Strategy (CWMS). The parties aim to develop solutions for water and land management.

The aim of this report is to describe the current knowledge of groundwater quality and chemistry within the OTOP area. It discusses groundwater quality and trends in the OTOP zone to support zone committee decision making. It also aims to highlight areas where groundwater quality is not suitable for certain uses, or where poor groundwater quality may affect groundwater-fed surface waters.

This report gives technical detail to support the groundwater resource summary produced by Zarour, *et al.* (2016). Companion reports on surface water hydrology (Dodson & Steel, 2016; Exner-Kittridge, 2016) and surface water quality and aquatic ecology (Hayward, *et al.,* 2016) are also available.

1.1 Study area

The study area (Figure 1-1) in this report covers most of the OTOP Canterbury Water Management Strategy zone, but excludes the northern catchments which flow directly into the Rangitata River. Figure 1-1 also shows groundwater provinces; hydrogeological subdivisions used in this report that do not have any planning or legal standings. Zarour, *et al.* (2016) define three groundwater environments in the OTOP study area and 11 groundwater provinces: Coastal Plains (Rangitata-Orton, Orari, Geraldine, and Opihi provinces), Downlands (Timaru, Pareora, Taiko Stream, and South Branch Pareora provinces) and Inland Basins (Ashwick Flat, Te Ana Wai[1], and Upper Pareora provinces). These are based on geological and hydrogeological commonalities.

[1] Te Ana Wai (or sometimes Te Ana a Wai) is the culturally appropriate name for the river and catchment. It was previously known as, and is on many maps as Tengawai (or Te Ngawai) after being incorrectly named by an early surveyor.

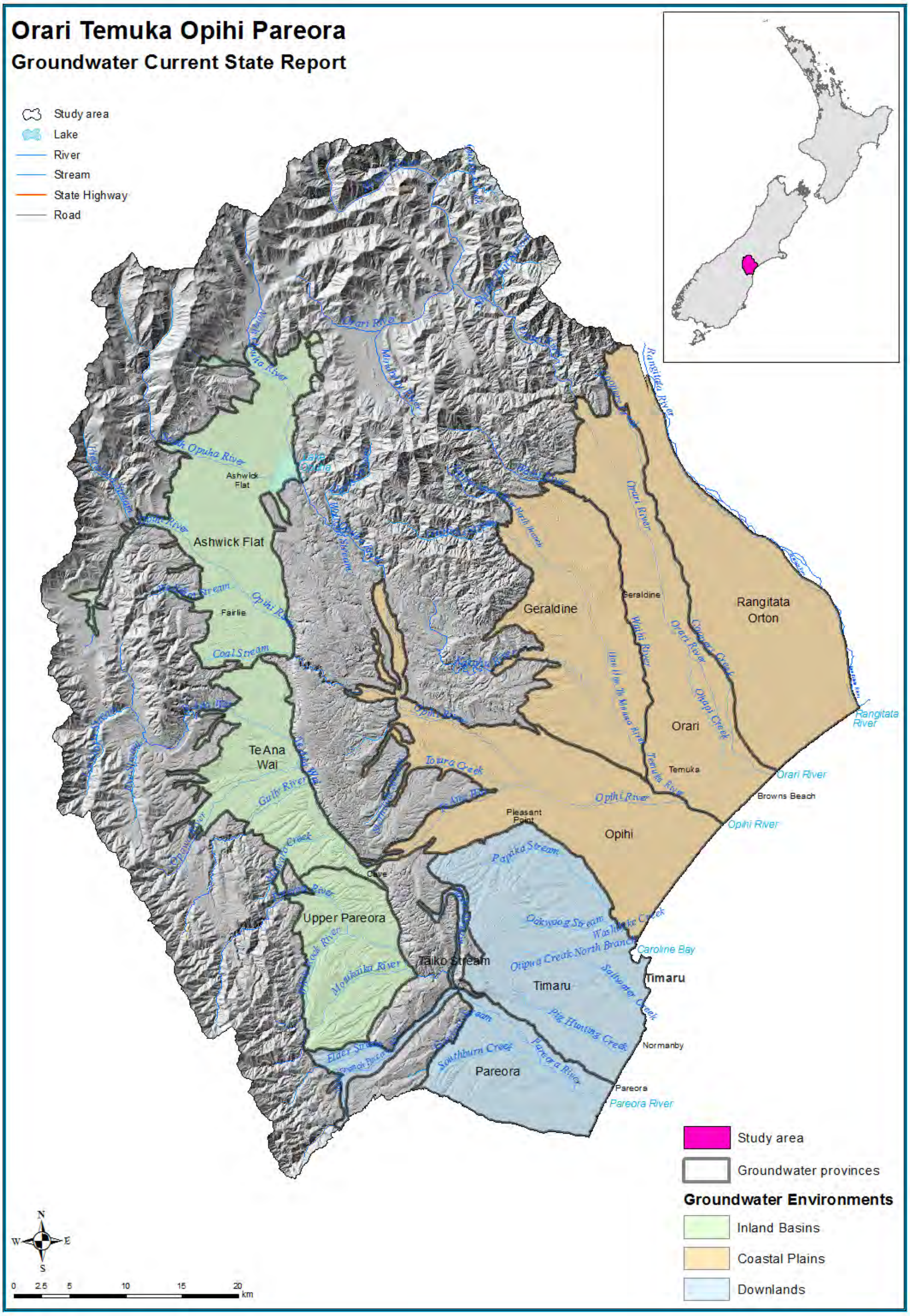

Figure 1-1: Study area location, groundwater environments, and groundwater provinces

1.2 Groundwater occurrence

Aitchison-Earl (2017) describes groundwater occurrence within the OTOP area. Torlesse greywacke forms the hydrogeological basement of OTOP. It does not have regionally significant groundwater resources. This basement rock is either exposed at the surface or covered by varying thicknesses of alluvium, colluvium, and loess. In parts of the OTOP area, directly overlying the basement are quartz conglomerate, sandstone, mudstone, and coal layers, collectively known as the Taratu Formation (locally known as the Broken River Formation). This is part of the Eyre Group. Few wells screen the Taratu Formation; near South Branch Pareora and Raincliff Stream catchments of our study area. There is limited use of this water due to its composition. The karstic limestone of the Kekenodon Group to the south of the Opihi and in the Pareora River province may also have a local groundwater flow system. White Rock Coal Measures and Southburn Sands of the Motunau Group have groundwater sufficient to be considered local aquifers. White Rock Coal Measures consist permeable bands of quartz gravels and sands, and occur locally inland of Pleasant Point, in the upper Te Ana Wai Basin, and Pareora catchment. The Southburn Sands consist fine sands and shell beds separated by beds of finer mudstone. The fine sands and shell beds hold groundwater and are locally utilised in the Pareora catchment.

Kowai Formation (locally known as Cannington Gravels) is a major groundwater resource in OTOP. In many areas it is likely hydraulically connected to younger overlying gravel layers. The Kowai Formation consists greywacke-derived fluvial gravel with clay, silt, and sand beds. In coastal areas the Kowai Formation has a deeper marine layer with many shells, overlain by a terrestrial layer. The Fairlie Basin has Kowai Formation deposits up to 150 m thick. Near Timaru and Geraldine several basalt flows overlie the Kowai Formation. These do not have a known groundwater resource but groundwater may be present within fractures.

Quaternary age deposits of gravel, sand, and silt overlie the Kowai Formation and basalt, and host the major groundwater resource across most of OTOP. These deposits occur in mostly flat areas and have higher permeability than older materials. Groundwater within Quaternary deposits occurs as unconfined to semi-confined aquifers which act as a single hydrostratigraphic system. Fan deposits occur on inland plains and beside the basement rock of the western ranges. They are thinner and of lower permeability than the river alluvium, but form discrete localised groundwater resources. Loess is windblown silt and is extensive below 800 m elevation, particularly around Timaru. It has low permeability which impedes recharge to underlying deposits. Holocene deposits are warm climate deposits composed of unweathered loose, gravel-dominated alluvium containing boulders, sand, silt, and clay. These deposits typically occur in present-day river courses and flood plains.

1.3 Groundwater recharge, discharge, and flow direction

Zarour, *et al.* (2016) describe groundwater recharge, discharge, and flow direction in more detail. Recharge sources across the study area include rainfall, rivers, and irrigation water. Land surface recharge (LSR) occurs where water percolates through soil into the underlying groundwater system. LSR often transports water-soluble contaminants applied or spilled onto land. LSR occurs when soil moisture exceeds the moisture-holding capacity of the soil and/or plant requirements, or through secondary flow paths such as macropores. Historically, constructed irrigation infrastructure was often leaky (including for the Rangitata South Irrigation Scheme (RSIS)), providing localised recharge to groundwater and diluting ion and contaminant concentrations in groundwater. Modern irrigation infrastructure attempts to minimise water losses from the delivery system to improve efficiency. River recharge occurs when hydraulic gradients lead to flow from surface water to groundwater. This recharge often has lower concentrations of dissolved ions and contaminants compared with LSR. There are downward vertical hydraulic gradients throughout most of the OTOP study area, suggesting downward movement of recharge into the groundwater system. Therefore, river recharge and LSR are important mechanisms affecting groundwater gradients and flow. The horizontal flow of groundwater tends to be from higher elevations inland, towards the coast. Groundwater flow direction often mimics changes in ground elevation (i.e. topography), and is influenced by surface water features (as recharge sources or discharge zones).

1.3.1 Coastal Plains

Beneath the Coastal Plains, groundwater flows in a south-easterly direction towards the coast, where it discharges to spring-fed streams, drains, or directly offshore. Near the coast, there is an upward hydraulic gradient; deeper groundwater has a higher head than shallow groundwater.

Groundwater and surface water exchanges are dynamic across the Coastal Plains

- rivers often lose water to groundwater as they emerge from impermeable hills and flow over permeable gravels
- the Orari River loses flow to groundwater above State Highway 1, some of which flows within a buried historic channel of the former Umukaha River, and resurfaces in springs of the Waihi River, Dobies Stream, Worners Creek, and Raukapuka Creek (Burbery & Ritson, 2010). In summer the Orari River can often be dry at State Highway 1 with flow resuming closer to the coast
- based on oxygen isotope data (e.g. ^{16}O: ^{18}O) there is some river water lost to the south of the Rangitata River, which travels towards the coast (Scott, *et al.,* 2011). Some shallow groundwater near the Rangitata River re-emerges as nearby McKinnons Creek (Burbery, 2012)
- the presence of basalt and faulting near Geraldine results in groundwater discharging into the Waihi River
- the Opihi River loses water to groundwater above the confluence with Te Ana Wai River and below Pleasant Point onto Levels Plain.

1.3.2 Inland Basins

In the Inland Basins the topography controls groundwater flow. LSR dominates and river recharge is limited to Holocene alluvium. Groundwater re-emerges as surface water at one of four exit points: Lake Opuha and the Opuha River, Opihi River at the gorge, Te Ana Wai River at the gorge, or Pareora River at the gorge.

1.3.3 Downlands

Groundwater flow across the Downlands is in a south-easterly direction towards the coast. There may be a groundwater divide where some groundwater flows towards Levels Plain. The Pareora River loses flow to groundwater on its north bank. Over 90% of the time, Pareora River flow is low enough that its mouth closes and flow drains through beach gravels offshore.

1.4 Land use

Figure 1-2 shows the land use types within OTOP based on AgriBase Dominant Farm Type data (accessed September 2017). As part of the OTOP sub-regional planning process this information was supplemented with consent data, valuation roll data, and Landcare Research's paddock-scale land cover classification. All farming and urban activities have the potential to cause groundwater pollution. The intensity of those activities, along with soil type, underlying geology, and climate, affects the level of contamination. We discuss these further in Section 4.

Cultural, socio-economic, and environmental conditions influence historical, current, and potential land use. For example, in Figure 1-2 on upland areas, where the soils are shallow and slopes steeper, sheep, beef, cattle and deer farming, native vegetation, and forestry predominate. Dairy farming covers the Coastal Plains, widely supported by irrigation. Irrigation usually supports more intensive land use and may lead to higher application rates of fertiliser and other nutrients as well as higher stocking rates. This in turn leads to greater leaching of contaminants into groundwater compared to less intensive land uses. Dairy farming or wintering of stock is often considered the most intensive land use, although previous investigations have also detected high contaminant concentrations in cropping areas (Hanson & Abraham, 2010).

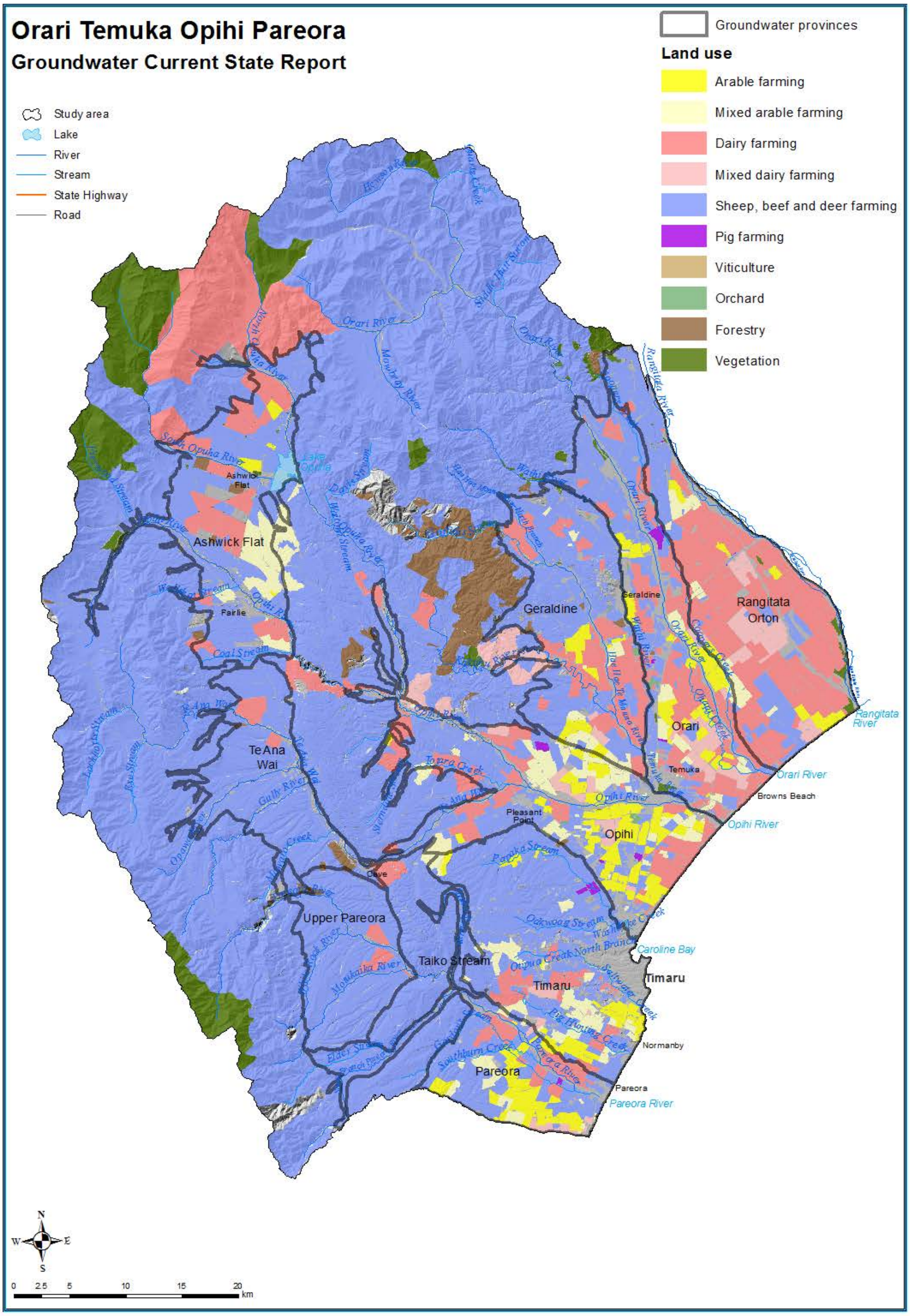

Figure 1-2: Land use types based on AgriBase Dominant Farm Type

1.5 Soil type

Soil has a fundamental influence on LSR flux, nutrient recycling and immobilisation, and contaminant leaching. Once drainage water and dissolved contaminants are below the rooting zone, they typically migrate into the underlying groundwater system. Therefore, understanding soil characteristics is an important aspect of groundwater quantity and quality studies. Soil also plays a fundamental role in land cover and use, which are also important in terms of groundwater recharge and an aquifer's vulnerability to contamination.

In Canterbury, we use the Matrix of Good Management (MGM) to estimate nitrogen and phosphorus losses below the root zone. The MGM uses simplified soil classifications for these estimates, based on the AgResearch S-map series. Figure 1-3 shows MGM nitrogen loss soil classes in the study area. Coastal and almost flat areas have a combination of light/very light/extremely light soils on river fans. These soils are the most prone to leaching of contaminants such as nitrate-N. Inter-fan areas, such as between the lower Orari and Opihi rivers and towards the coast, have medium/deep/heavy soil types. Extensive less-permeable fragipan occurs on the Downlands and is usually associated with loess deposits. The lower permeability has a controlling influence on LSR to groundwater and increases surface runoff in these areas. Loess soils (including fragipan layers) direct runoff and subsoil lateral flow to surface water or low-lying areas. Extensive areas of poorly drained soils in Orari, Geraldine, and Opihi provinces may promote low dissolved oxygen (DO) concentrations, which can lead to denitrification and mobilisation of metals.

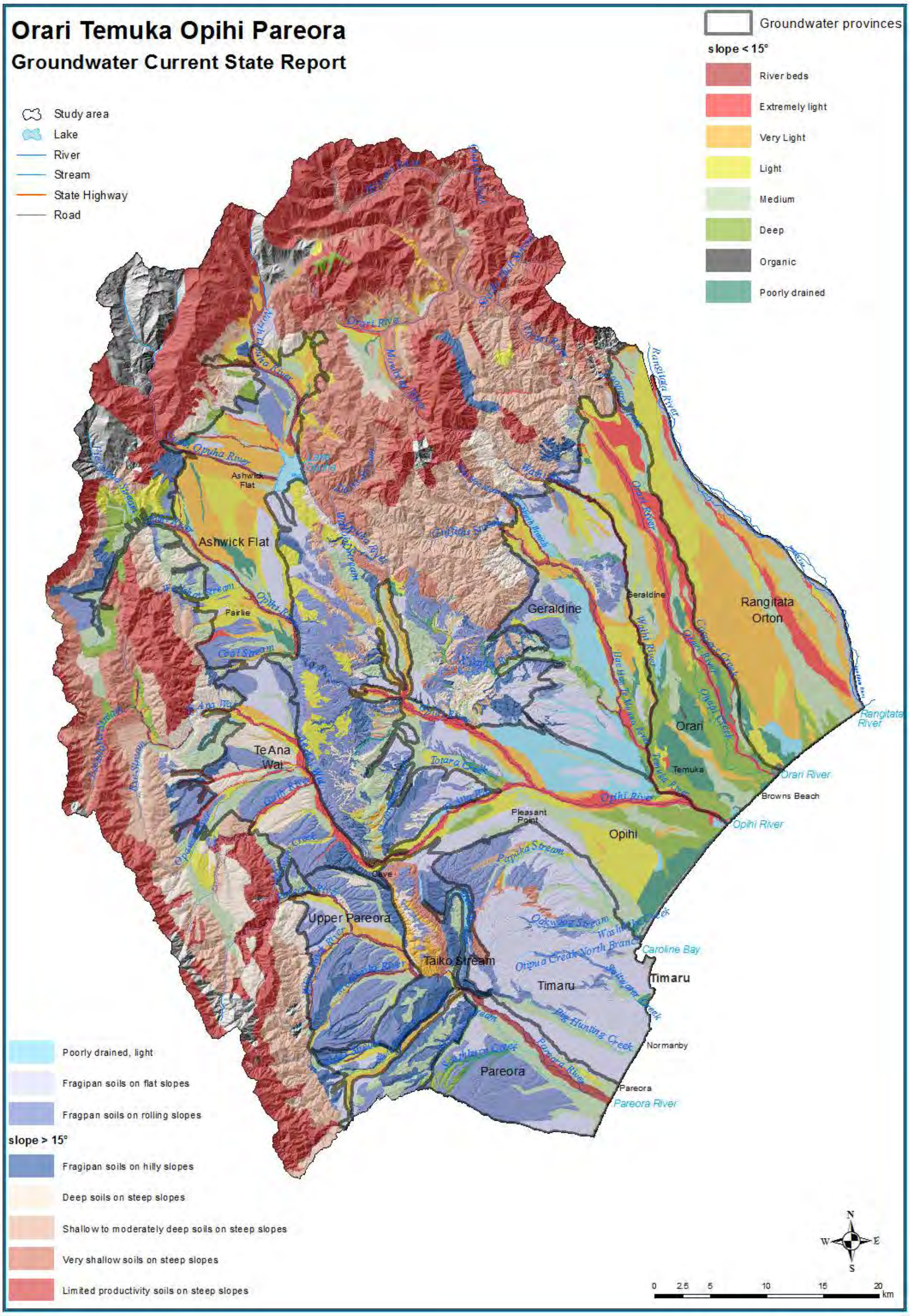

Figure 1-3: MGM soil nitrogen loss classes

1.6 Irrigation

Rainfall across OTOP is not enough to meet natural evapotranspiration demand during summer across most of the low-lying area. Irrigation is therefore necessary to support crop health and productivity. Irrigation can also increase land use intensity, which may lead to increased leaching of contaminants (such as nitrate-N), especially when coupled with high fertiliser application rates and/or stocking rates.

Irrigation occurs across 13% of the OTOP area, including 25% of all irrigable land (Zarour, *et al.,* 2016). Figure 1-4 shows the locations of irrigated land, irrigation scheme extent, and irrigation scheme water distribution infrastructure. Storage ponds and distribution races can be leaky and provide additional recharge to groundwater. Leakage from irrigation infrastructure locally reduces concentrations of contaminants due to dilution. Conversions from border-dyke to spray irrigation generally reduces groundwater recharge, and increases concentrations of groundwater contaminants due to less dilution.

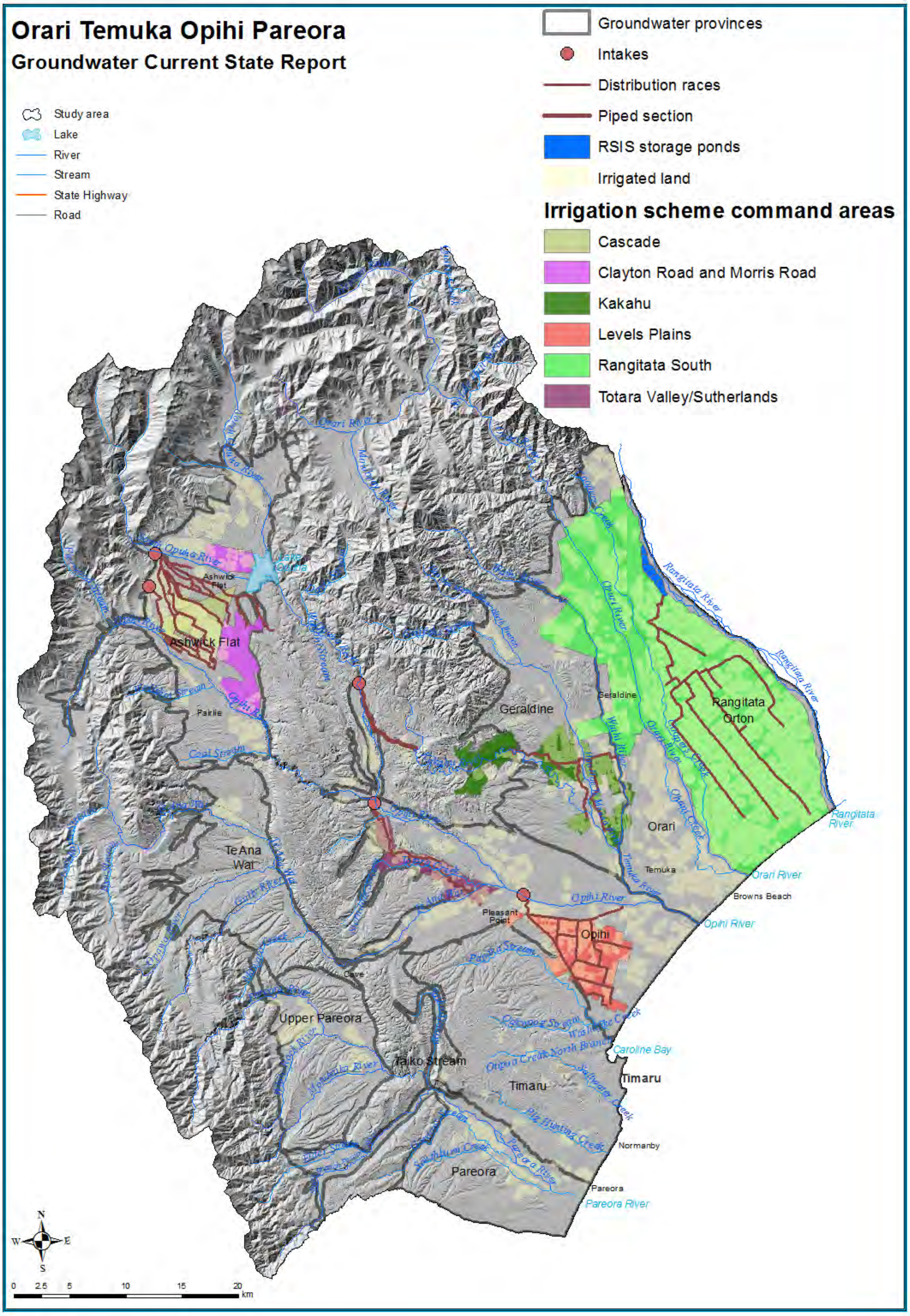

Figure 1-4: **Irrigated land, irrigation scheme extent, and irrigation scheme water distribution infrastructure**

1.7 Data sources and long-term monitoring

There are over 3,000 wells in the study area. Environment Canterbury has one or more groundwater quality record for 490 of these wells.

Environment Canterbury samples groundwater in the OTOP area on a regular basis to monitor and establish temporal trends. Forty-six wells are part of Environment Canterbury's long-term monitoring networks (Figure 1-5). Another well monitors potential contamination from a fertiliser storage site, which was previously a fertiliser manufacturing site. Environment Canterbury staff sample 17 of the monitoring wells every three months to monitor seasonal nitrate-N variations. Two of these are sampled monthly to give more information on the timing and magnitude of short-term changes in nitrate-N concentrations. Five of these 17 wells are also part of our seawater intrusion monitoring network, which aims to give early indication of a landward shift of the fresh water/seawater interface.

As needed, Environment Canterbury conducts targeted investigations of groundwater quality to improve understanding of groundwater in OTOP. Investigations include:

- Burbery and Ritson (2010): an integrated study of surface water and shallow groundwater resources of the Orari catchment
- Burbery and Vincent (2009): the hydrochemistry of Tertiary aquifers in South Canterbury
- Burbery and Abraham (2016): use of groundwater quality data to investigate recharge and discharge mechanisms and flow dynamics for deep groundwater in South Canterbury
- Hayward and Smith (1999): hydrocarbon contamination in groundwater in Washdyke
- Kaelin, *et al.* (2016): impacts of the Rangitata South Irrigation Scheme on the groundwater system
- Scott, *et al.* (2011): groundwater impacted by consented activities between the Rangitata and Orari rivers
- Smith (1993b): groundwater contamination from activities at the Seadown Fertiliser storage on Levels Plain
- Smith (1993a): Triazine pesticides on Levels Plain
- Stewart (2004; 2006) and van der Raaij (2007; 2009; 2010; 2016): groundwater age dating
- Wong (2015): filling gaps where groundwater quality data was not available.

Many consent holders are also required to submit groundwater quality data to Environment Canterbury where consent conditions impose monitoring requirements.

For most of our analysis we use water quality data that includes long-term monitoring data, consents data, and data collected during investigations. We use some of Environment Canterbury's surface water quality data to aid in the interpretation of groundwater-surface water interactions. The minimum criteria for data inclusion is a single sample from a well. We average duplicate data and assigned non-detect values half of the laboratory detection limit (which is the accepted approach). Results with known errors were removed from the dataset. We use all data up to May 2016, except

- nitrate-N temporal trends include data up to August 2017
- iron and manganese data are up to August 2017 and exclude data before 2000 due to unreliability
- DO data are up to August 2017 and exclude data before 2005 due to unreliability.

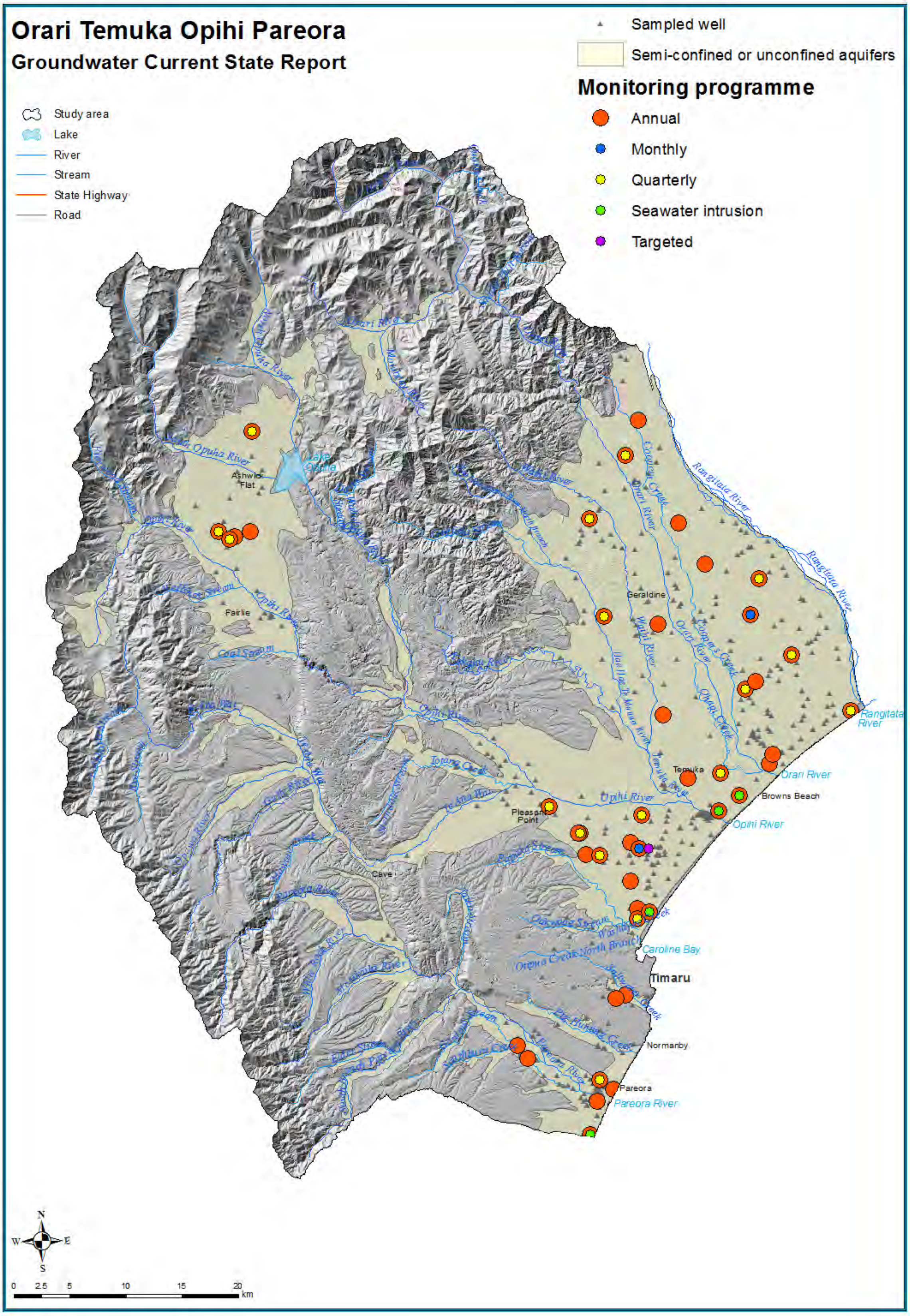

Figure 1-5: **Locations of long-term groundwater quality monitoring wells and wells with water quality data available. Tan areas are probable groundwater occurrence**

2 Groundwater chemistry

Burbery and Vincent (2009) describe chemical composition of groundwater as dependent on many factors, including:

- composition of the aquifer material through which it flows
- composition and type of recharge source (i.e. river recharge versus LSR)
- mean residence time of the water
- contamination from land-use activities
- chemical reaction processes occurring within the aquifer (e.g. ion exchange and redox)
- groundwater flow path and mixing processes (e.g. infiltration of rainfall and/or irrigation water).

We use groundwater chemistry to investigate the processes and dynamics of OTOP hydrological systems.

2.1 Oxygen-18

Oxygen-18 isotope ratio ($\delta^{18}O$) is a measure of the relative concentrations of two stable isotopes of oxygen: ^{18}O and ^{16}O. This ratio is useful in tracing the source(s) of recharge to groundwater[2]. Inland areas or high-altitude catchments will have a more negative $\delta^{18}O$ than areas receiving coastal recharge. Figure 2-1 shows typical ranges of $\delta^{18}O$ within our study area.

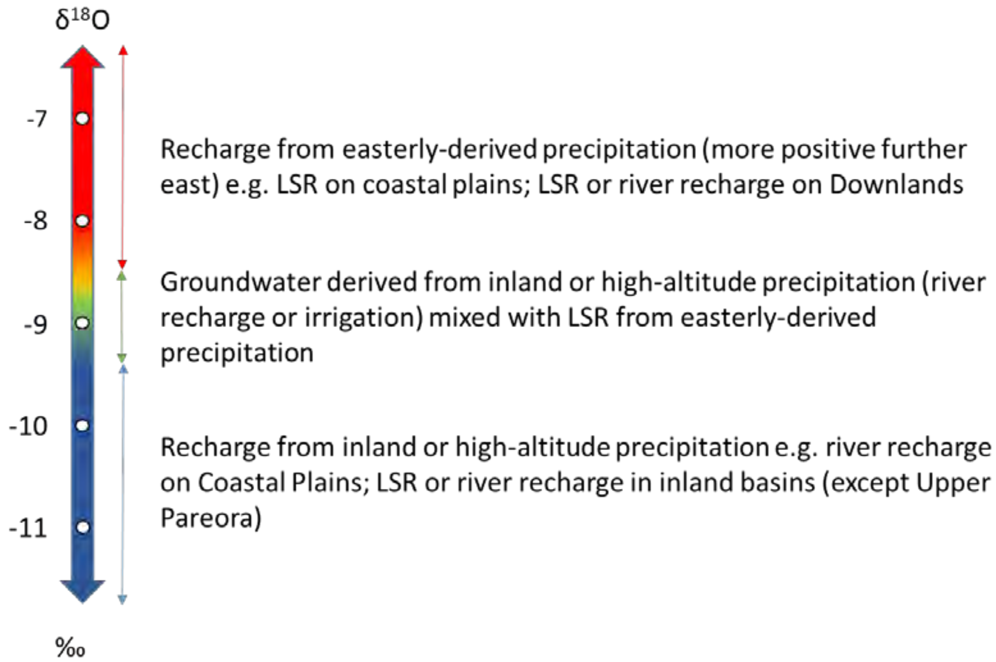

Figure 2-1: Typical ranges of $\delta^{18}O$ within the study area

Scott (2014) summarised the $\delta^{18}O$ data available for groundwater in Canterbury, including the study area. Since then, Environment Canterbury staff have performed sampling (Wong, 2015), focusing on areas that have not been sampled before. Figure 2-2 summarises available $\delta^{18}O$ data (groundwater and surface water) as at August 2017.

[2] For a more detailed explanation of methods, refer to Scott (2014)

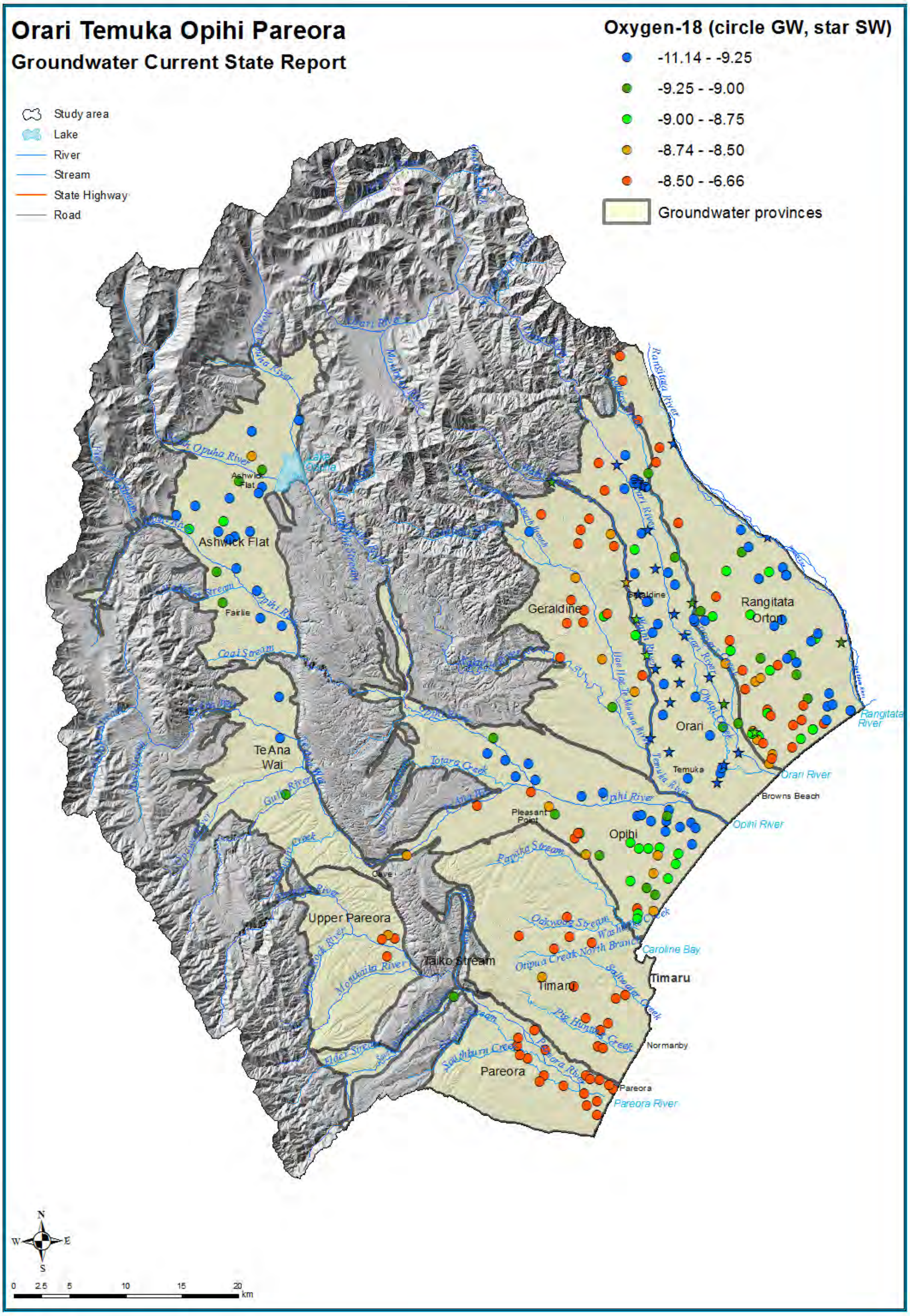

Figure 2-2: Average $\delta^{18}O$ for groundwater (circles) and surface water (stars)

2.1.1 Coastal Plains

LSR on the Coastal Plains is driven by rainfall from easterly weather systems as shown by the generally more positive $\delta^{18}O$ signatures. Inland Coastal Plains areas may not receive significant recharge from rivers beyond the extent of the young alluvial deposits, so LSR dominates recharge. By province:

- **Rangitata-Orton:** Rangitata River recharges groundwater along the Holocene deposits of the south riparian zone. LSR dominates the rest of the province, with more negative $\delta^{18}O$ signatures due to irrigation with river waters and/or leakage from water races.

- **Orari:** Orari River is the dominant recharge source.

- **Geraldine:** Basalt outcrops are a barrier to shallow groundwater flow, with groundwater discharging into the Waihi River resulting in a more positive $\delta^{18}O$ signature in the river. More $\delta^{18}O$ samples are needed to determine interactions in the lower part of the province.

- **Opihi:** Opihi River recharges groundwater on the south and north banks. $\delta^{18}O$ patterns suggest on Levels Plain, Opihi River recharge dominates its northern part while LSR dominates the south. The $\delta^{18}O$ for groundwater is more negative either due to mixing with water from leaky water races (holding Opihi River water) or mixing of river water and LSR. The high $\delta^{18}O$ on the south bank of Te Ana Wai River suggests that it is dominated by LSR.

2.1.2 Inland Basins

The groundwater in Ashwick Flat and Te Ana Wai provinces has more negative $\delta^{18}O$ compared with the Upper Pareora province. This is due to the former provinces being further inland and having higher altitudes, while easterly weather systems dominating the latter. It is not possible to differentiate LSR and river recharge based on $\delta^{18}O$ alone for any of the provinces. By province:

- **Ashwick Flat:** High nitrate-N concentrations (Section 4.4.4) indicate that the province receives significant LSR.

- **Te Ana Wai:** Only one shallow well has $\delta^{18}O$ data. Along with median range $\delta^{18}O$ it also had slightly elevated nitrate-N indicating some component of LSR.

- **Upper Pareora:** A small part of its catchment is at higher elevation that could result in lower $\delta^{18}O$ value. $\delta^{18}O$ are slightly more negative than near the coast. Elevated nitrate-N in a shallow well indicates LSR.

2.1.3 Downlands

The Downlands are dominated by easterly weather systems as shown by the more positive $\delta^{18}O$ signatures. By province:

- **Taiko Stream:** No wells sampled.

- **South Branch Pareora:** One well has been sampled. This deep well is screened in the Taratu Formation where groundwater age is over 43,000 years. Its more negative $\delta^{18}O$ may be due to recharge during colder climatic conditions.

- **Timaru:** It is not possible to differentiate LSR and river recharge based on $\delta^{18}O$ alone. Evaporation of the recharge water results in a more positive $\delta^{18}O$ signature. This may be related to ponding on the land surface where loess occurs and the slow recharge rates through thick loess deposits.

- **Pareora:** It is not possible to differentiate LSR from river recharge based on $\delta^{18}O$ alone as the Pareora River has a similar $\delta^{18}O$ to groundwater with LSR. Other parameters indicate that the north bank of the Pareora River receives river recharge whereas the south bank has a LSR signature.

2.2 Groundwater age

Groundwater age estimates are based on various natural and anthropogenic tracers present in water at the time it becomes groundwater. The concentrations of some tracers reduce over time, due to natural decay. Concentrations of other tracers increase due to human influences. Concentrations of tracers enables groundwater age estimates (Stewart & Morgenstern, 2001). Age estimation methods are complex due to variation in anthropogenic tracers over time and mixing of waters from recharge sources at the time of sampling. For discussions and interpretations of groundwater age data, please refer to Stewart (2004; 2006) and van der Raaij (2007; 2009; 2010; 2016). Figure 2-3 shows the locations of all wells for which we have age data together with the well depths. Age estimation is often reported as a range of ages together with uncertainties. For ease of understanding, we have simplified this by using a single number to represent an approximate age for each sample.

2.2.1 Coastal Plains

Rangitata-Orton and Orari provinces have the most representative data. Young groundwater occurs in areas of river recharge and inland areas of LSR. Near the coast, shallow groundwater can become aged. Similarly, deep groundwater (where it does not receive river recharge) tends to be aged. By province:

- **Rangitata-Orton:** Shallow wells have very young groundwater. There are also some deep wells near rivers that receive rapid recharge. In areas dominated by LSR, groundwater is older in deeper wells and wells further along the flow path and towards the coast (Scott, *et al.,* 2011). Groundwater in one shallow well near the coast is dated at around 50 years. Scott, *et al.* (2011) propose that this is due to upwelling of older groundwater near the coast, a theory supported by upward hydraulic gradients.

- **Orari:** Near the upper part of the province two deep wells have been dated at around 110 years. Based on their $\delta^{18}O$ signature they likely represent a mix of river recharge and LSR. Shallow groundwater halfway down the province receives Orari River recharge. Age here is less than 1 year. Groundwater from a 62 m deep well near the coast has been dated at over 110 years, while a groundwater sample from a 54 m deep well further up the catchment has been dated at about 60 years. This indicates that while the recharge from the river may be rapid, the flow of deeper groundwater may not be as rapid as in the Rangitata-Orton province.

- **Geraldine:** No wells sampled.

- **Opihi:** One sample has been collected (from J38/0040). Groundwater in this 55 m deep well has been dated at over 110 years. Tritium dating has an upper limit of about 110 years and the water could be much older than this. This well is screened in an aquifer where groundwater is recharged by LSR through loess.

2.2.2 Inland Basins

Only one province in this environment has been age dated, so conclusions relating to groundwater age need to be informed by other chemistry data. By province:

- **Ashwick Flat:** No wells sampled. Based on high nitrate-N concentrations (Section 4.4.4), we expect shallow groundwater to be quite young.

- **Te Ana Wai:** No wells sampled. Stiff diagrams for deep groundwater (Section 2.3) indicate ion exchange which requires long residence times.

- **Upper Pareora:** Groundwater from a shallow well has been dated at less than one year, indicating rapid recharge. Two deep wells have groundwater dated at 12,000 and 23,000 years, indicating slow recharge and discharge of deep groundwater.

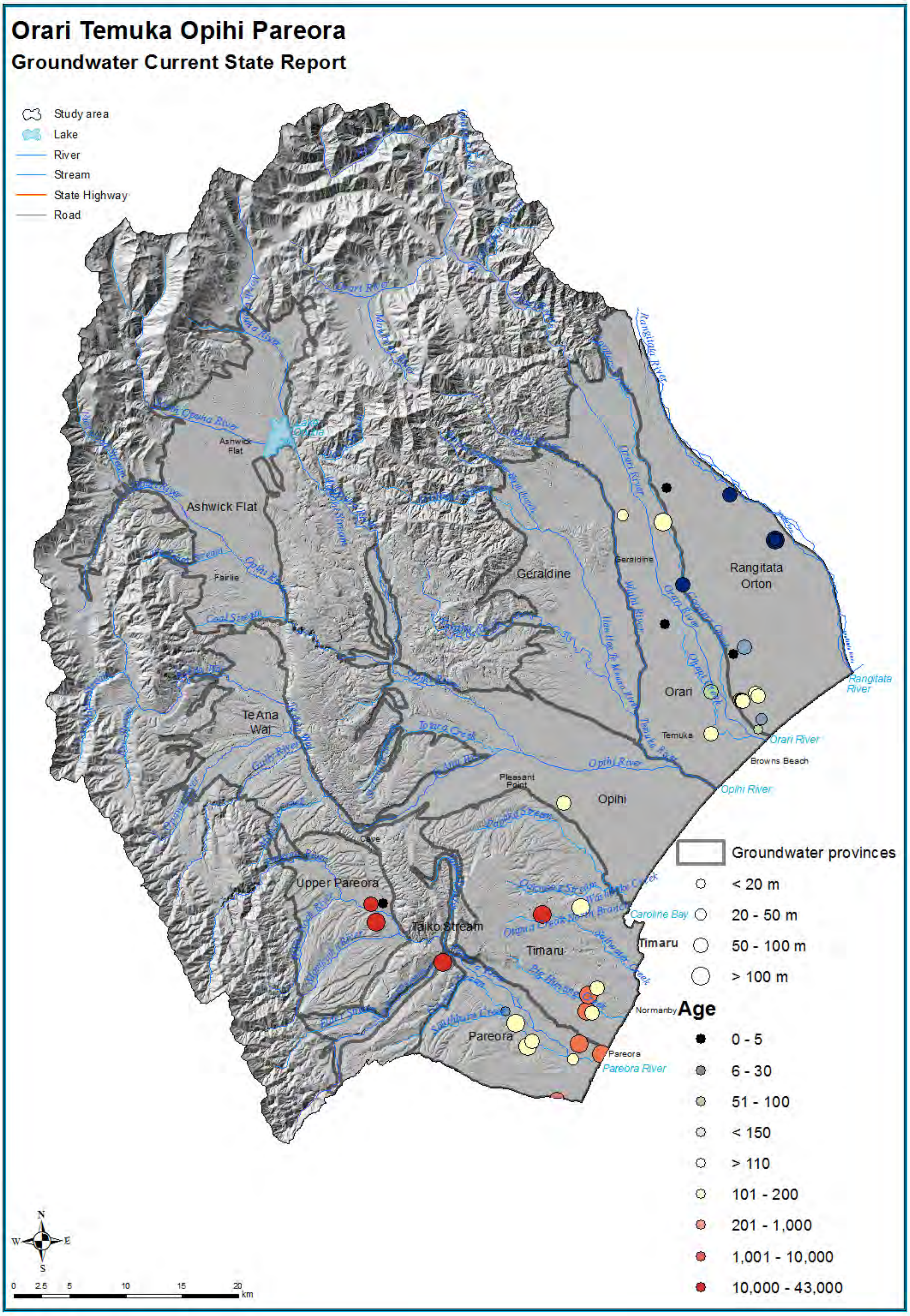

Figure 2-3: Groundwater age estimates for wells of different depth

2.2.3 Downlands

Deep groundwater in this environment is thousands to tens of thousands of years old. Because of its greater geological complexity, it is possible that there is greater stratification of the groundwater system and discrete flow paths in this groundwater environment. By province:

- **Taiko Stream:** No wells sampled.

- **South Branch Pareora:** Groundwater in one deep well (screening the Taratu Formation) has been dated at over 43,000 years. This groundwater has very high dissolved ions and the water is likely to be very old LSR that that has undergone ion exchange.

- **Timaru:** Deep groundwater is thousands of years old. South of Timaru, deep groundwater becomes older with distance south and towards the coast. Groundwater from J39/0679 (60 m deep) is less than 150 years despite being close to J39/0663 (159 m deep) with groundwater of 1,500 years. This indicates stratification or preferential recharge in locations. Groundwater from a deep well west of Timaru is 12,000 years; the oldest water in the province. This, along with the differences in water chemistry, indicates a complex and partially stratified system.

- **Pareora:** Deep wells to the north of the river screen very old groundwater; thousands of years old. Groundwater from J39/0904 (146 m deep) is 4,200 years, while groundwater in another well closer to the coast (J39/0009; 139 m deep) is 5,500 years. Age dating of shallow groundwater has not been performed, but since there is recharge from the river to the north, we expect it to be young. To the south of the river, groundwater from one deep well is 200 years, and two others less than 150 years[3]. Groundwater from shallow well J39/0109 (13 m deep) is 30 years. The older age in shallow groundwater may be due to thick layer(s) of clay or an alternate recharge source. Because of elevated nitrate-N concentrations in shallow groundwater, it is unlikely that it will be very old as it receives more LSR than to the north of the river.

2.3 Stiff diagrams

Stiff diagrams are a graphical representation of major ion composition in a water sample. Stiff diagrams allow for quick visual comparison of different samples. The cations are plotted on the left-hand side and anions on the right, both in milliequivalents per litre. Similar diagram shapes indicate similar recharge sources. The different colours represent different water types and the size reflects the concentrations of the ions. The relative amounts of ions can provide a rough proxy for groundwater age as longer contact with aquifer sediments will allow for more minerals to dissolve. As a general principle, younger groundwater has lower concentrations of ions as it has less time to react with aquifer minerals. Older, slow moving groundwater has higher ion concentrations with the ionic composition reflecting the more soluble minerals of the deposit in which it is located. The presence of greywacke in Canterbury can confound this, because it consists inert silicate minerals which undergo limited (if any) dissolution. This means that ion concentrations in old groundwater can still be very dilute. Because there is little interaction with the greywacke, the proportions of ions in alluvial gravel aquifers rely more on recharge water composition than aquifer composition.

We construct Stiff diagrams as Burbery and Abraham (2016) did to allow easy comparison. Their study area covered the Downlands and Levels Plain, but did not include the rest of the Coastal Plains or the Inland Basins environments. Figure 2-4 shows the Stiff diagram map for the sampled groundwater within the study area. Appendix A contains separate Stiff diagram maps for the Coastal Plains, Inland Basins, and Downlands. Appendix A also displays deep (> 20 m) and shallow (≤ 20 m) wells separately.

[3] Note < 150 years can represent an age from 0 to 149 years old

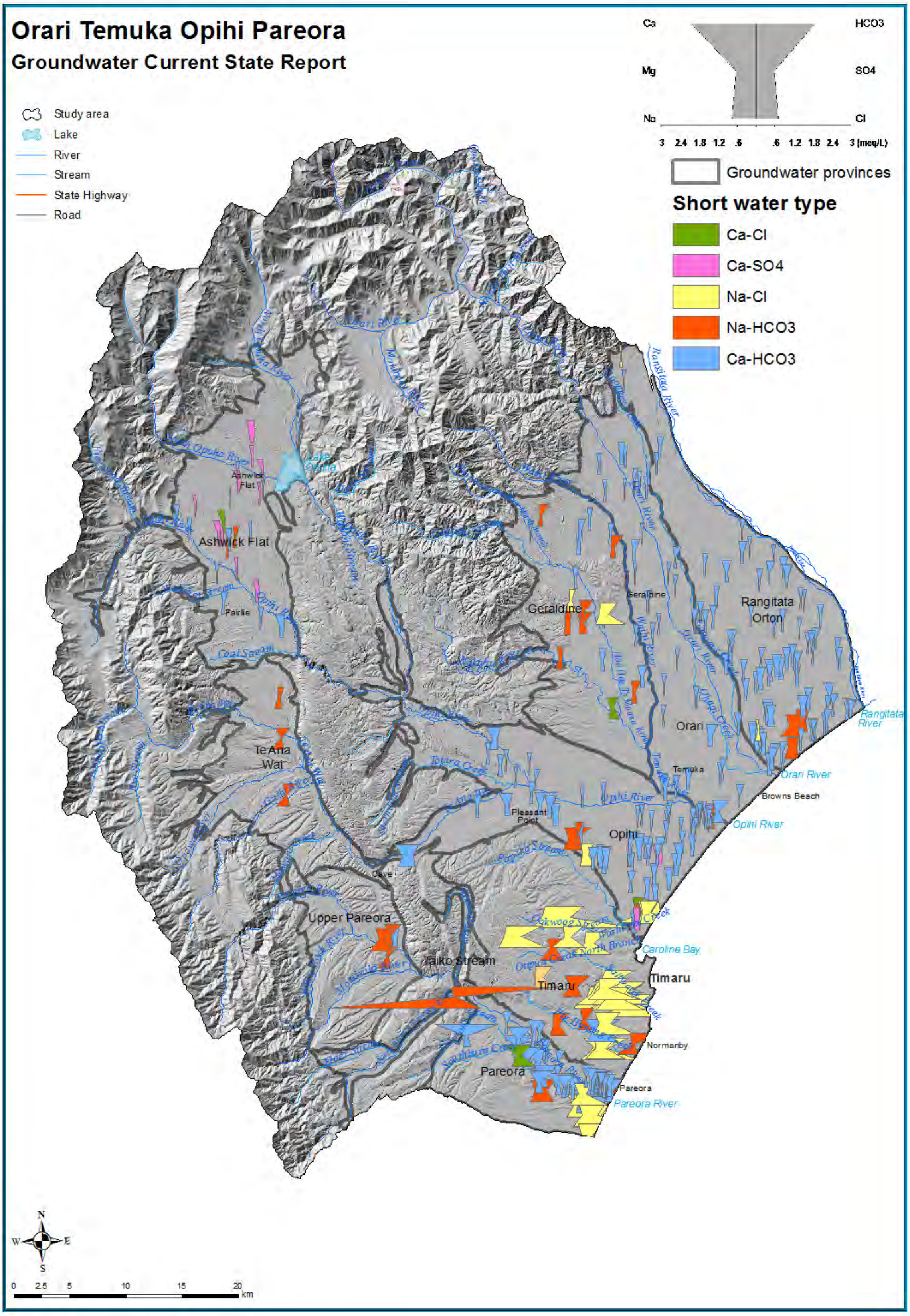

Figure 2-4: **Stiff diagrams for sampled groundwater. I omitted four wells for clarity**

2.3.1 Coastal Plains

Calcium bicarbonate (Ca-HCO_3) type groundwater dominates the Coastal Plains due to calcite dissolution; calcite makes up a small percentage (< 3%) of Rakaia Terrane rocks (Jacobsen, *et al.,* 2003). 'Skinny' blue diagrams with low ion content represent areas dominated by river recharge, such as near the Opihi, Orari and Rangitata rivers. Fatter diagrams reflect LSR. By province:

- **Rangitata-Orton:** Most groundwater is Ca-HCO_3 type. Deep groundwater has 'fatter' Stiff diagrams compared to shallow groundwater in similar locations. This is due to longer residence time and greater opportunity for water to interact with rock materials. A result with Na-Cl type water and low dissolved ions at the western inland area of the province may be due to local recharge or show land use effects, as this sample is from a very shallow well (2 m) near the Clandeboye dairy factory.

  Scott, *et al.* (2011) analyse Stiff diagrams in the area influenced by Clandeboye dairy factory discharges and found that groundwater downgradient from the discharge was high in sodium and chloride ions. They also note that groundwater in areas with reducing conditions had high bicarbonate and low nitrate-N and sulphate. Groundwater downgradient from the discharges have Na-HCO_3 type water with Stiff diagrams like wastewater as described in Scott, *et al.* (2011). One sample near the factory returned as Sodium Chloride (Na-Cl) type groundwater. This may be due to disposal or leakage of condensate water.

- **Orari:** All wells have Ca-HCO_3 type groundwater. Stiff diagrams are skinny indicating short residence times. In the western inland area of the province, fatter Stiff diagrams indicate LSR. Deeper groundwater with longer residence times also has fatter Stiff diagrams. One shallow well located near Winchester, contains groundwater with a fatter Stiff diagram and low nitrate-N concentrations, possibly due to denitrification, but the higher ions are likely due to land use impacts. The groundwater with the fattest Stiff diagram is near the coast and is deep. This likely represents old groundwater.

- **Geraldine:** A mix of water types reflect more complex geology. Some areas have Na-Cl type groundwater. Burbery and Abraham (2016) identify this as being characteristic of LSR on the Coastal Plains where loess occurs. This groundwater type reflects the higher silt and clay mineral content of loess. Ca-HCO_3 type groundwater occurs near rivers or in the area northwest of Geraldine, which is likely to be dominated by LSR but is not covered in loess. There are also several occurrences of Na-HCO_3 type water. Burbery and Abraham (2016) postulate that this is old groundwater with Na and HCO_3 content increasing due to feldspar weathering. This groundwater also has high silica concentrations, supporting their hypothesis. There is one shallow well with Ca-Cl type groundwater. Burbery and Abraham (2016) suggested that either seawater intrusion or land use impacts may result in this type of chemistry. This well is too far inland for seawater intrusion to occur. It is possible that the Na-Cl type water from recharge on loess-covered areas could be a source of dilute seawater for reverse ion exchange to occur.

- **Opihi:** Ca-HCO_3 type groundwater dominates the province. Burbery and Abraham (2016) conclude that Levels Plain groundwater has similar chemistry to irrigation water, with varying sulphate from fertiliser usage. Environment Canterbury has carried out additional sampling in this province since Burbery and Abraham's analysis. These data indicate that on Levels Plain, the area within the Holocene age alluvium is dominated by Opihi River recharge (skinny Stiff diagrams), while other areas are dominated by LSR (fatter Stiff diagrams) with some leakage from irrigation infrastructure. Two deep wells with Ca-HCO_3 type groundwater have slightly different shapes with higher concentrations of HCO_3 and silica.

  There are a number of local variances from this overall trend. Three shallow wells near Waipopo have Na-HCO_3, Ca-Cl and Ca-SO_4 type groundwater, reflecting land use impacts. Downgradient from the Seadown fertiliser storage facility a well with Ca-SO_4 type groundwater reflects impacts from this activity. Na-Cl type groundwater from a 24 m deep well near loess soils likely represents LSR recharge through the loess. Two deep wells with Na-HCO_3 type groundwater represent old water with increasing Na and HCO_3 content due to feldspar weathering; differing Stiff diagrams may represent a slightly different recharge source or mixed waters. Three shallow wells with Na-HCO_3, Ca-Cl and Ca-SO_4 type groundwaters in Washdyke likely reflect land use impacts, including that from industry, point and diffuse discharges. Near Washdyke Lagoon and the coast, two deep and

one shallow well have Na-Cl type groundwater, possibly reflecting seawater intrusion effects, or a discharge area for deeper and older LSR from further inland. Northwest of Washdyke Lagoon, along the Opihi River, groundwater in Holocene age alluvium is dominated by river recharge (skinny Stiff diagrams), while the area south of Te Ana Wai River is dominated by LSR (fatter Stiff diagrams).

2.3.2 Inland Basins

Na-HCO_3 type groundwater is present across all three provinces, while Ca-HCO_3 is present in both Ashwick Flat and Upper Pareora provinces. The presence of Na and HCO_3 suggests older groundwater that has undergone ion exchange and/or feldspar weathering. By province:

- **Ashwick Flat:** Ca-SO_4 type groundwater dominates. Natural state water is Ca-HCO_3 so the SO_4 is likely from fertiliser usage. One shallow well has Na-HCO_3 type groundwater with a very skinny Stiff diagram. This could represent South Opuha River water leaking from the irrigation infrastructure which would have low ion concentrations. There is also one shallow well with Ca-Cl type groundwater which also has very high nitrate-N concentrations and indicates land use effects. Discharges for human and animal effluent occur upgradient of this well; one or both could be the cause of this variation in water type.

- **Te Ana Wai:** The two deep and one shallow well have Na-HCO_3 type groundwater. This indicates slightly aged groundwater recharged through loess.

- **Upper Pareora:** One shallow well has Ca-HCO_3 type groundwater. Three deep wells have Na-HCO_3 type groundwater. Burbery and Abraham (2016), conclude that this is indicative of long residence times and feldspar weathering, and is supported by age dating. The higher chloride content from one of the three deep wells may indicate LSR recharge through loess as marine deposits (that contain chloride-rich organics) are absent in this province.

2.3.3 Downlands

The greater geological complexity of the Downlands (as compared to the other groundwater environments) means limited inferences across all three provinces can be drawn. Deep groundwaters from the Timaru and Pareora provinces have high chloride concentrations, reflecting the marine geology. There is evidence of LSR across all three provinces but the signatures are not consistent. By province:

- **Taiko Stream:** No wells sampled.

- **South Branch Pareora:** One well has been sampled for ionic composition. This deep well is screened in the Taratu Formation. This groundwater has very high dissolved ions and Na-HCO_3 type groundwater. Age dating indicates this groundwater is more than 43,000 years old (van der Raaij, 2009). Burbery and Abraham (2016) describe this type of water as very old LSR that has undergone ion exchange. This aquifer is likely to be disconnected from the Kowai Formation.

- **Timaru:** Burbery and Abraham (2016) describe generally Na-Cl type groundwater from LSR. Surface waters such as Saltwater Creek are also dominated by Na-Cl type water. Burbery and Abraham (2016) note that groundwater in this area is high in most major ions except for potassium and sulphate. From our analysis, the concentrations of sulphate in loess areas are higher than in other deep wells within the study area. Burbery and Abraham also postulate that the exposed headland increases sea spray and thus chloride. There are no geological sources or sinks for chloride in the study area, so it is likely the elevated concentrations result from partially evaporated sea spray. Evaporation occurs in places such as depressions on loess, which hold water after heavy rainfall (Poulsen, 2013). We exclude four wells (K39/0066, K39/0067, K39/0068, J39/0297) with Na-Cl type groundwater from Figure 2-4 for clarity as these wells have very high Na-Cl concentrations. The first three are located near a landfill in Timaru and close to Saltwater Creek and the coast and the fourth may be impacted by a septic tank.

  Burbery and Abraham (2016) also note elevated magnesium near the Timaru basalt and one deep well with Mg-Cl type groundwater. Other wells in the Timaru province have a Na-HCO_3 groundwater

type and some are screened in the lower Kowai Formation. Burbery and Abraham (2016) identify this as old groundwater with increasing Na-HCO_3 content, conceivably from chemical weathering of Na-feldspar in greywacke sediments. These wells have lower concentrations of chloride compared with the Na-Cl type groundwater, so may have a different recharge source. Burbery and Abraham (2016) postulate that the lower Kowai Formation groundwater originates from LSR at a formation exposure immediately west of Levels Plain. Age determination does not necessarily support this. Wells between Timaru and Pareora show increasing age in the southerly direction but their Stiff diagrams indicate different sources of recharge. A 36 m deep well near the coast has Na-HCO_3 type groundwater, which according to Burbery and Abraham (2016) is indicative of very old LSR which has undergone ion exchange. This could be very old water upwelling near the coast. The low chloride concentration relative to other wells could indicate a different recharge source to other deep wells nearby, or a mixing zone between shallow groundwater and upwelling deeper groundwater.

There are two wells with Ca-HCO_3 type groundwater in the Timaru province. One very deep well (CA19/0009) appears to have a Stiff diagram similar to the Pareora River. Burbery and Abraham (2016) postulate that Pareora River water enters the lower Kowai Formation much further up the catchment and that Pig Hunting Creek follows a paleochannel of the Pareora River. The second well (J39/0663) has a 'fat' Stiff diagram which is quite different to the Pareora River water. According to Burbery and Abraham (2016) the high Na-Cl content indicates water of LSR origin, whereas the high Ca-HCO_3 is from shell material in the lower Kowai Formation.

- **Pareora:** Ca-HCO_3 type groundwater dominates the province. Burbery and Abraham (2016) note the Pareora River recharges groundwater to considerable depths. Shallow and deep groundwater have similar composition implying short residence time. However, because the deep groundwater is anoxic they suggest it is aged groundwater. Since their work, age dating has supported their hypothesis.

  Groundwater on the southern side of the Pareora River has higher Ca-HCO_3 concentrations compared with the north side. This is due to the influence of Gordons Stream, which has limestone deposits in its catchment. Burbery and Abraham (2016) postulate that rapid vertical transport into sediments of the lower Kowai Formation occurs, which may be partly induced by pumped abstraction. This theory is based on groundwater from a deep well with elevated nitrate-N concentrations and Ca-Cl type water, located inland and away from any conceivable seawater intrusion. Burbery and Abraham (2016) also note stratification of the groundwater near the coast. A groundwater sample from a 40 m deep well (J39/0516), screened in the upper Kowai Formation, has Na-Cl type groundwater sourced from LSR on the loess Downlands, while nearby shallow wells have Ca-HCO_3 type groundwater sourced from the Pareora River. Groundwater from other shallow wells near the loess also had Na-Cl type water, sourced from recharge through the loess.

2.4 Electrical conductivity

Electrical conductivity (EC) is the measure of the ability of water to carry an electrical charge. It is related to concentrations of dissolved ions. High EC can be due to natural sources or result from human land uses, such as application of fertilisers and effluent to land. EC values can be used to inform recharge sources, especially when combined with knowledge of EC in surface waters. EC can support our interpretations based on $\delta^{18}O$ signatures and provide additional information. Figure 2-5 and Figure 2-6 show EC concentrations in groundwater and surface waters respectively.

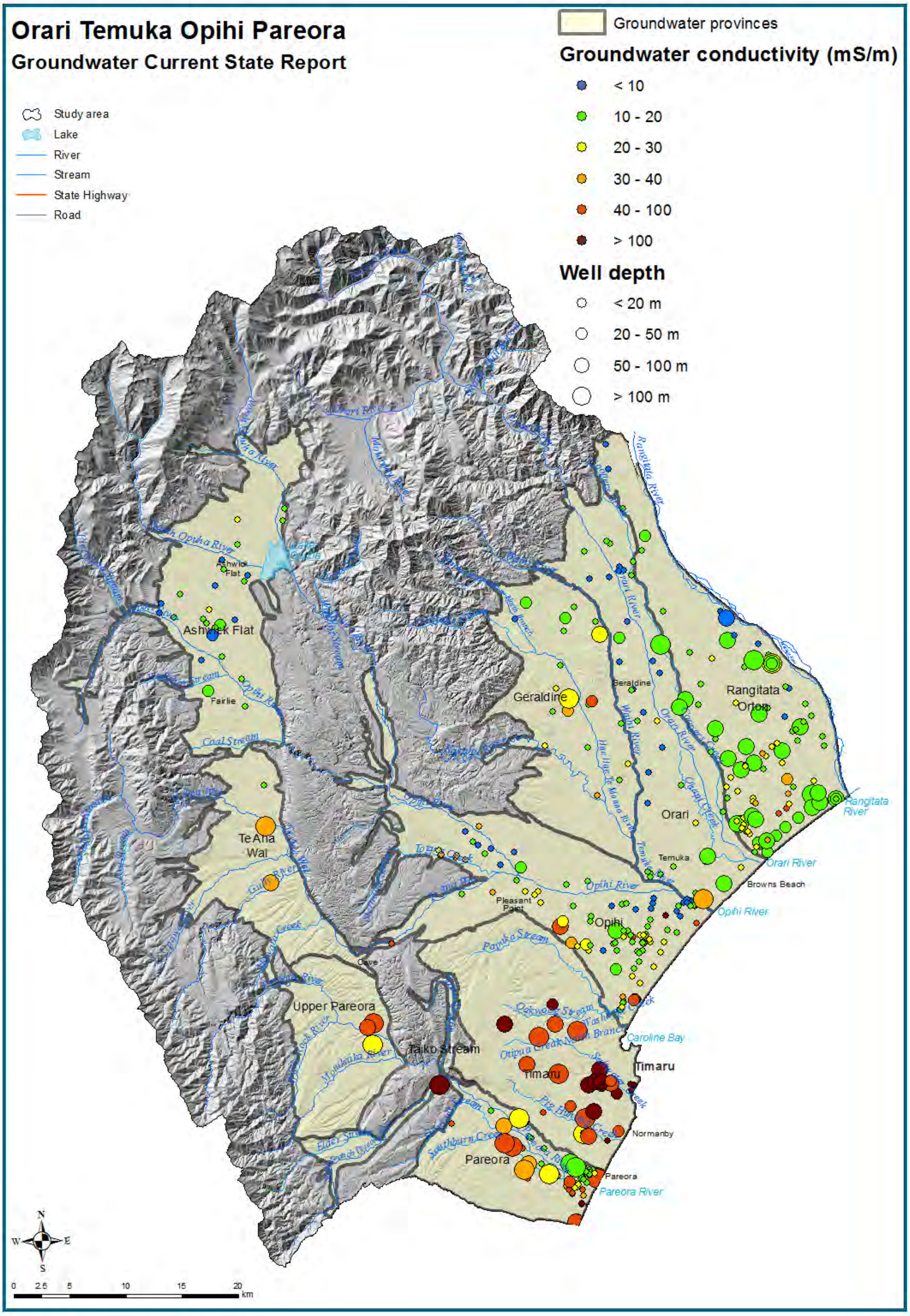

Figure 2-5: Average conductivity in groundwater

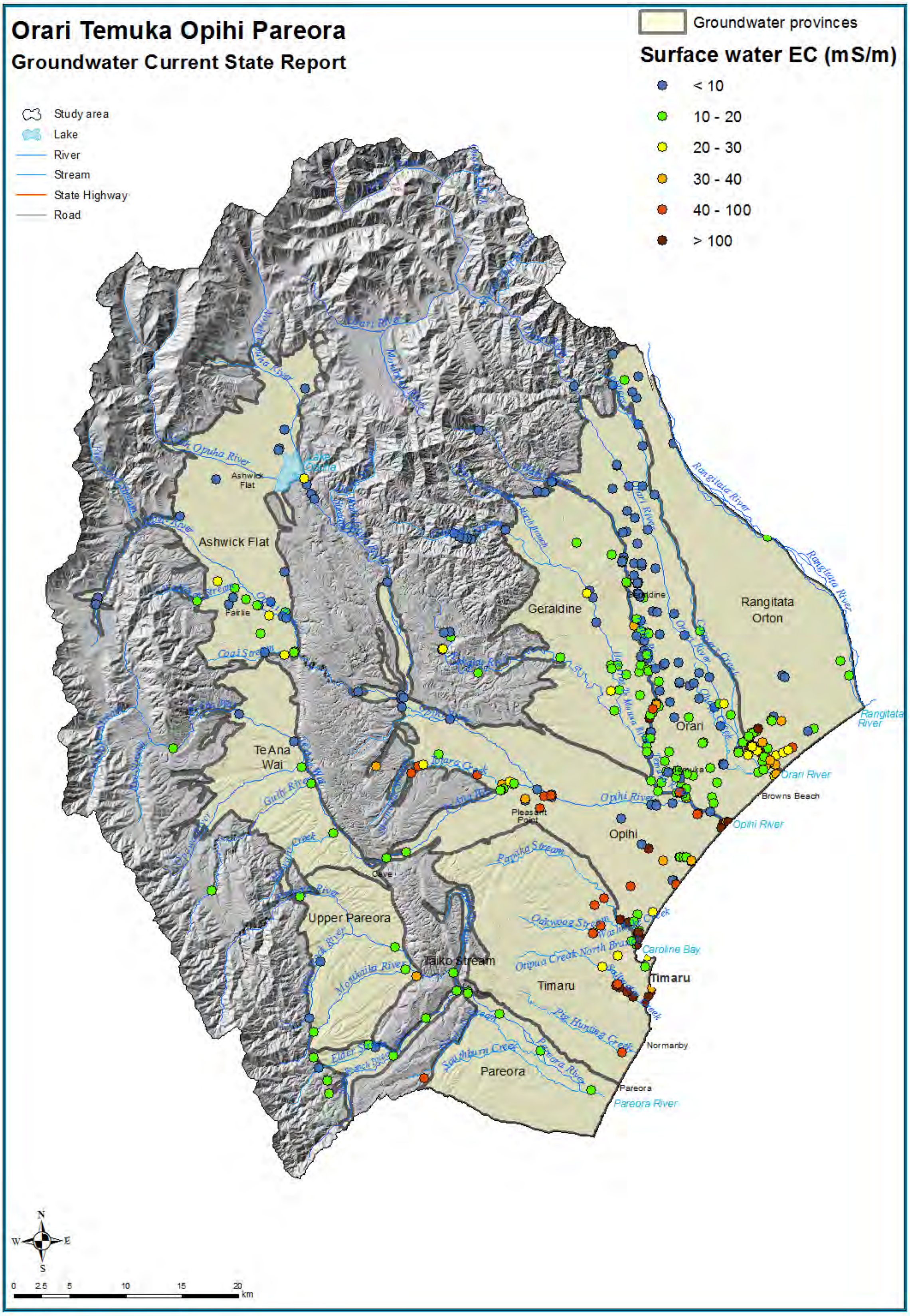

Figure 2-6: Average conductivity in surface water

2.4.1 Coastal Plains

Across this groundwater environment, EC values near the coast tend to be elevated reflecting higher concentrations of dissolved ions from sea spray. Across the inland areas of the provinces, high EC values indicate LSR dominance where there is a lack of river recharge (as indicated by low EC). By province:

- **Rangitata-Orton:** Groundwater near the Rangitata River has low EC, indicating river recharge. The rest of the province is dominated by LSR. EC is elevated in groundwater where Clandeboye dairy factory irrigates land with wastewater.

- **Orari:** Groundwater receives most recharge from river losses. Closer to the coast EC is slightly higher, suggesting an increasing part of LSR or longer residence time.

- **Geraldine:** LSR dominates groundwater recharge. Rivers such the Waihi and Hae Hae Te Moana do not provide significant recharge to groundwater. Lower in the province, streams and drains have similar conductivities to groundwater indicating groundwater discharge into surface waters. Deeper groundwater has higher EC indicating longer residence times. As per the findings of Burbery (2012) basalt is unlikely to be the cause of elevated EC as it is rich in quartz and resistant to weathering.

- **Opihi:** Low EC values near the south bank of the lower Opihi River reflect river recharge. Further upstream, low EC indicates that the river may also recharge local groundwater on both banks. High EC values in Totara Creek may be due to geological deposits such as limestone. High EC near Pleasant Point and Levels Plain is due to LSR. Some wells near Washdyke Lagoon have higher EC reflecting of the estuarine location of the Lagoon during the Holocene, or saltwater intrusion. EC is also higher in some deeper wells near loess-covered areas where LSR dominates.

2.4.2 Inland Basins

Surface water across the provinces have similar ECs. Groundwater in this environment tends to have higher EC than surface water due to LSR. By province:

- **Ashwick Flat:** EC in surface water is low due to the inland location and lack of geological sources of ions. EC is higher in groundwater than surface water due to LSR dominance and land use effects.

- **Te Ana Wai:** One shallow well has EC measurements. Values were low, but higher than those from Te Ana Wai River. The two deeper wells have higher EC that may indicate aged groundwater.

- **Upper Pareora:** One shallow well has EC measurements. These are higher than those in surface water. This, together with elevated nitrate-N in the shallow well, indicates LSR and land use effects. The deep wells have higher EC measurements and are likely to have aged groundwater.

2.4.3 Downlands

Groundwater in the Downlands has higher EC due to longer residence times and greater variability in soils and geology enabling greater dissolution of minerals, that increases EC. Variability in EC, in both shallow and deep groundwater, is due to differing recharge sources. By province:

- **Taiko Stream:** No wells sampled.

- **South Branch Pareora:** One well has EC data. This deep well is screened in the Taratu Formation, dated at over 43,000 years, and has a high EC of 280 mS/m. This potentially reflects the marine environment of the Formation. The EC in surface water is low and similar to that of the provinces in the Inland Basins.

- **Timaru:** Both groundwater and surface water have elevated EC. Burbery and Abraham (2016) suggest this is due to sea spray on the prominent basaltic headland. It is also possible that because of the local soils and geology (i.e. loess) water seeps in slowly and evaporation and transpiration by

plants concentrates dissolved salts, increasing EC. Some of the deeper wells have lower EC than shallow wells indicating a different recharge source or that the groundwater pre-dates the land use effects.

- **Pareora:** Groundwater on the north bank of the Pareora River receives river recharge. Burbery and Abraham (2016) note that deep groundwater has the same ionic composition as shallow groundwater, but may be much older due to low concentrations of DO. Thick layers of clay affect recharge patterns and groundwater movement. Two deep wells near the coast have high EC and major ions (Section 2.2). This could suggest a different recharge source with a greater LSR component, saltwater intrusion, or screening in marine deposits. EC in groundwater is higher on the south bank of the Pareora River than on the north bank. Due to the limestone deposits EC in Gordon Stream is higher resulting in higher shallow groundwater EC.

2.5 Dissolved oxygen

DO is an important indicator of groundwater reduction-oxidation (redox) state. This is of interest because it controls the fate of several natural and man-made contaminants in groundwater. Oxygen is supplied to groundwater by recharge of oxygenated water or by movement of air through the unsaturated material above the groundwater table. DO is important because of its role in various biochemical processes. Its absence can allow other processes to occur. DO can be consumed through biodegradation leading to low concentrations in groundwater. Low DO can then allow denitrification to take place. Denitrification is a process where nitrate-N is converted to other nitrogen species, reducing nitrate-N concentrations in groundwater. Low DO concentrations in groundwater tend to correspond to areas where groundwater flow is slow (i.e. old groundwater) and/or where the aquifer contains organic deposits (e.g. peat or effluent contamination). Quaternary-age outwash gravels are characterised by low organic matter. Rivett, *et al.* (2008) reported that concentrations of less than 1 mg/L of DO may be required for denitrification to occur. However, in some studies denitrification was observed at DO concentrations between 1 and 4 mg/L. We therefore use three DO concentration ranges in Figure 2-7: < 1 mg/L where denitrification is possible, 1 – 4 mg/L where some denitrification could be possible, and > 4 mg/L where denitrification is unlikely. Figure 2-7 shows minimum DO concentrations recorded for each well, although some wells may have had higher DO concentrations at other times. We use the minima from the last 10 years of data as older DO data are not as reliable.

We divide the wells into different depth ranges in Figure 2-7 because deeper wells are more likely to intercept older groundwater with low DO concentrations. Areas with higher quantities of electron donor species in the aquifer materials (e.g. organic matter, ferrous iron minerals or sulphide minerals) can also result in low DO due to oxidisation of material.

2.5.1 Coastal Plains

DO concentrations in shallow groundwater are high across this environment, except in areas of poorly drained soil and/or intensive land use. By province:

- **Rangitata-Orton:** Some shallow wells near the lower Orari River have lower concentrations (< 1 – 4 mg/L). Because deeper groundwater has high DO concentrations, it is unlikely that the lower DO is from upwelling groundwater. Instead, it is more likely that either the poorly drained soils or land use activities produce conditions suitable for microbial action, which reduces DO concentrations in groundwater. There is also an area near Clandeboye with low DO concentrations due to wastewater discharges from the dairy factory (Scott, *et al.,* 2011).

- **Orari:** A couple of the shallow wells in the upper and most shallow wells in the lower province have groundwater with low DO concentrations. Deep groundwater in this province has lower DO concentrations.

- **Geraldine:** Groundwater with high DO appears to correspond with lighter soils or rivers which may act as recharge sources, while groundwater with low DO corresponds with poorly-drained or fragipan soils.

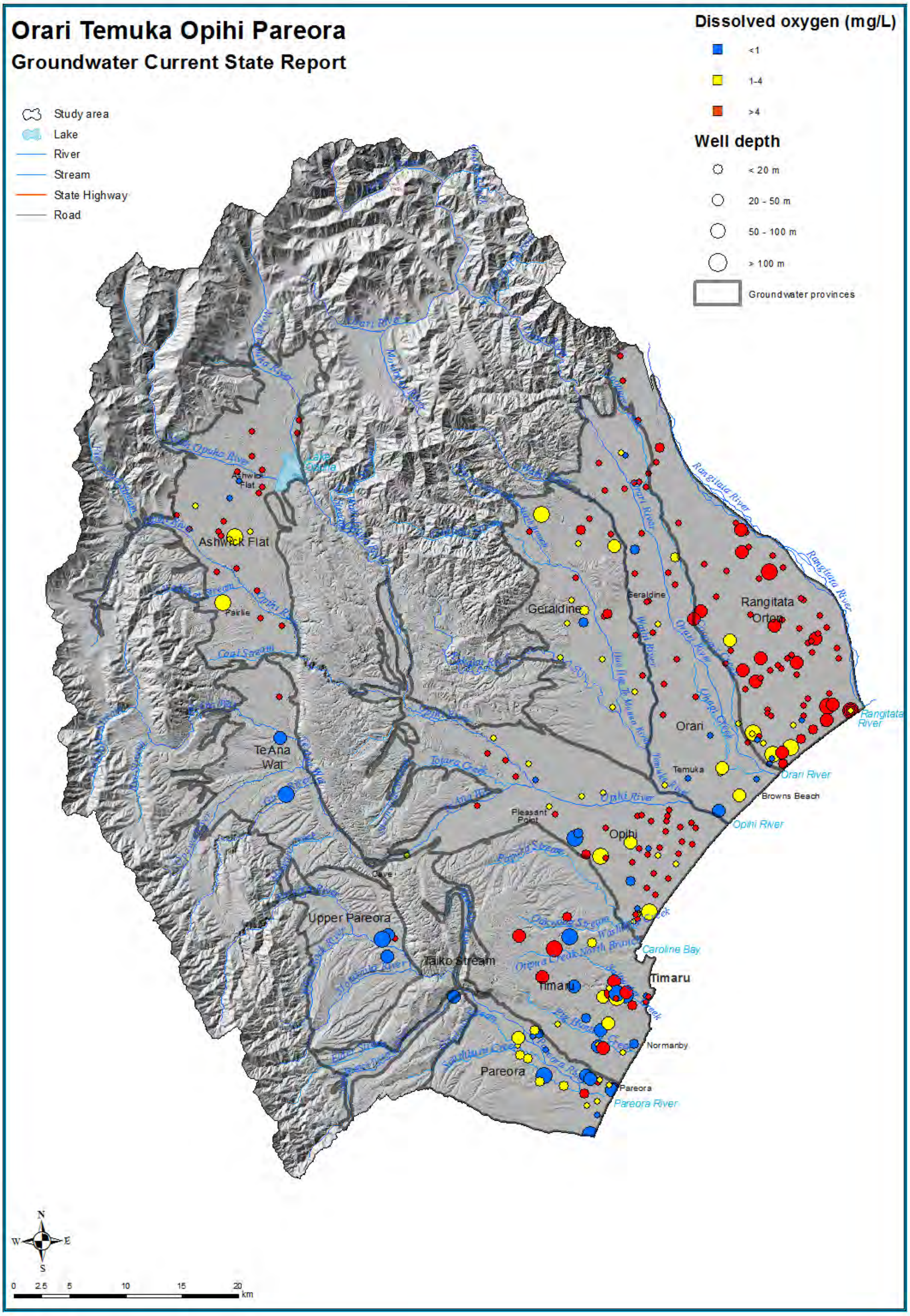

Figure 2-7: Minimum dissolved oxygen concentrations in wells (since 2005)

- **Opihi:** Shallow groundwater with low DO may be natural due to poorly drained soils while in others it may be due to discharge sources (e.g. downgradient from the Seadown fertiliser storage). Most deeper wells have lower DO concentrations in their groundwater, indicating longer flow paths and older groundwater.

2.5.2 Inland Basins

As with the Coastal Plains, shallow groundwater in the Inland Basins is high in DO. Deeper groundwater has comparatively lower concentrations. By province:

- **Ashwick Flat:** Some shallow wells have samples that exhibit significant fluctuations in DO concentrations. This includes concentrations suitable for denitrification.

- **Te Ana Wai:** One shallow well has a single DO measurement. This groundwater has high DO, which indicates young water and fast recharge. DO samples from deep groundwater has low concentrations, indicating aged groundwater and slow recharge.

- **Upper Pareora:** Four wells have been sampled for DO. The groundwater from the shallow well (hidden behind deep wells in Figure 2-7) had high DO concentrations. Groundwater from the three deep wells had low DO concentrations and age dating indicates this groundwater is thousands of years old (van der Raaij, 2009).

2.5.3 Downlands

Shallow groundwater in the Downlands has lower DO concentrations than the previous two environments. By province:

- **Taiko Stream:** No wells sampled.

- **South Branch Pareora:** One deep well has low DO concentration groundwater, consistent with its old age.

- **Timaru:** Groundwater from the shallow well has mid-range DO concentrations. Groundwater from the deep wells has a mix of low and high DO concentrations with no obvious way to explain the distribution of the results. There may be areas where there are preferential pathways for recharge. Groundwater from one of the deep wells that has high DO has been dated at about 12,000 years (van der Raaij, 2009). This indicates that there is either mixing of some very old and younger (high DO) water, there is no electron donor, or the DO measurements were not correct.

- **Pareora:** The minimum concentrations of DO for shallow groundwater are generally quite low. However, sampled wells have large variations in their measured DO concentrations and at other times their DO is quite high. This may be following recharge events, after which the DO concentrations may reduce, either due to biological activity or mixing with low DO water. The DO concentrations in deep groundwater are low or mid-range. Two of the deep groundwater wells with low DO, located on the north bank of the river and near the coast, have very old groundwater.

2.6 Iron, manganese, and arsenic

Iron, manganese, and arsenic occur naturally in groundwater in some areas. They originate from aquifer minerals and can convert to more soluble species in areas with low DO concentrations. Their source can also be anthropogenic, such as landfills, sheep dips, or even well casings.

The interconversions of these elements between soluble and insoluble forms depend on the pH and redox potential of groundwater. Redox potential is a measure of the tendency of a chemical species to acquire an electron. The redox status of groundwater affects the solubility of iron, manganese and arsenic. Low DO concentrations are required for the more soluble species to be mobilised from organic materials.

The amount of dissolved iron, manganese and arsenic in groundwater may vary seasonally due to an influx of oxygenated water during periods of high recharge. This oxygenated recharge will prevent dissolution of ions from organic material. After the oxygen in the recharge water has been consumed reduced conditions prevail, and iron, manganese, and arsenic can be mobilised in groundwater. Oxidation of manganese is significantly slower than iron. This may mean that high manganese concentrations persist for longer even if groundwater DO increases.

Both iron and manganese are essential elements required in small amounts by all living organisms. Arsenic may also be an essential element. At higher concentrations, these elements can cause aesthetic and health problems. Figure 2-8 shows the maximum iron and manganese concentrations measured in groundwater in the study area since 2000.

There are 34 wells (of 246) whose groundwater had iron concentrations that exceeded the GV of 0.2 mg/L (set by Ministry of Health (2008) for aesthetic reasons) at some stage. Many wells with iron concentrations above the GV had minimum DO concentrations below 4 mg/L. Groundwater with fluctuating levels of DO tend to have periods where conditions allow iron to dissolve.

42 (of 246) wells had manganese concentrations that exceeded the GV of 0.04 mg/L (set by Ministry of Health (2008) for aesthetic reasons). Of those, groundwater from 9 wells also exceeded the MAV of 0.4 mg/L (set by Ministry of Health (2008) for health reasons). Many of the wells whose manganese concentrations exceed the GV have low minimum DO concentrations (below 4 mg/L). As with iron, fluctuating DO concentrations result in conditions where manganese could dissolve.

One groundwater sample within the study area exceeds the arsenic MAV of 0.01 mg/L set by Ministry of Health (2008) for health reasons at 0.041 mg/L. Highest arsenic concentrations occur in the Timaru province, coinciding with areas of development.

2.6.1 Coastal Plains

Local conditions along the Coastal Plain result in exceedances of GVs and MAVs for both iron and manganese. These conditions include anthropogenic sources such as the Clandeboye dairy factory or Seadown fertiliser storage discharges, and natural sources such as old swamp deposits, poorly drained soils, loess, and Kowai Formation. Fluctuating DO concentrations resulting in anoxic conditions also allow increases in concentrations. By province:

- **Rangitata-Orton:** Has low iron and manganese concentrations. In lower parts of the province, some groundwater is anoxic; conditions that could result in higher iron and/or manganese concentrations. These areas tend to coincide with the lower Orari River where old swamp deposits occur, or are downgradient from the Clandeboye dairy factory discharges. Groundwater in a shallow well downgradient from the dairy factory exceeds the MAV for manganese. Groundwater near the Rangitata River has high iron concentrations. Borelogs suggest an absence of organic matter which could cause this. As this groundwater is young (even in deep wells) and DO was not measured when the samples were collected it is possible that the total iron instead of dissolved iron was measured, and that the oxidised well casing has affected the sample.

- **Orari:** In this province there are some shallow wells whose groundwater has manganese concentrations exceed the GV, and one whose groundwater has exceeded the MAV. The wells are not consistently above these values and variations in DO concentrations indicate that at times the groundwater conditions become anoxic.

- **Geraldine:** Shallow and deep groundwater has exceedances of iron GV and/or manganese MAV. Groundwater from one shallow well exceeds the MAV for manganese. In shallow groundwater these exceedances tend to be in samples from wells located in or near areas with poorly drained soils, loess, or Kowai Formation exposures. Loess contains minerals of the epidote group, which contain iron (Raeside, 1964). Groundwater from deep wells is likely to represent aged anoxic groundwater. The Kowai Formation is cemented by clays and iron oxides (Forsyth, 2001).

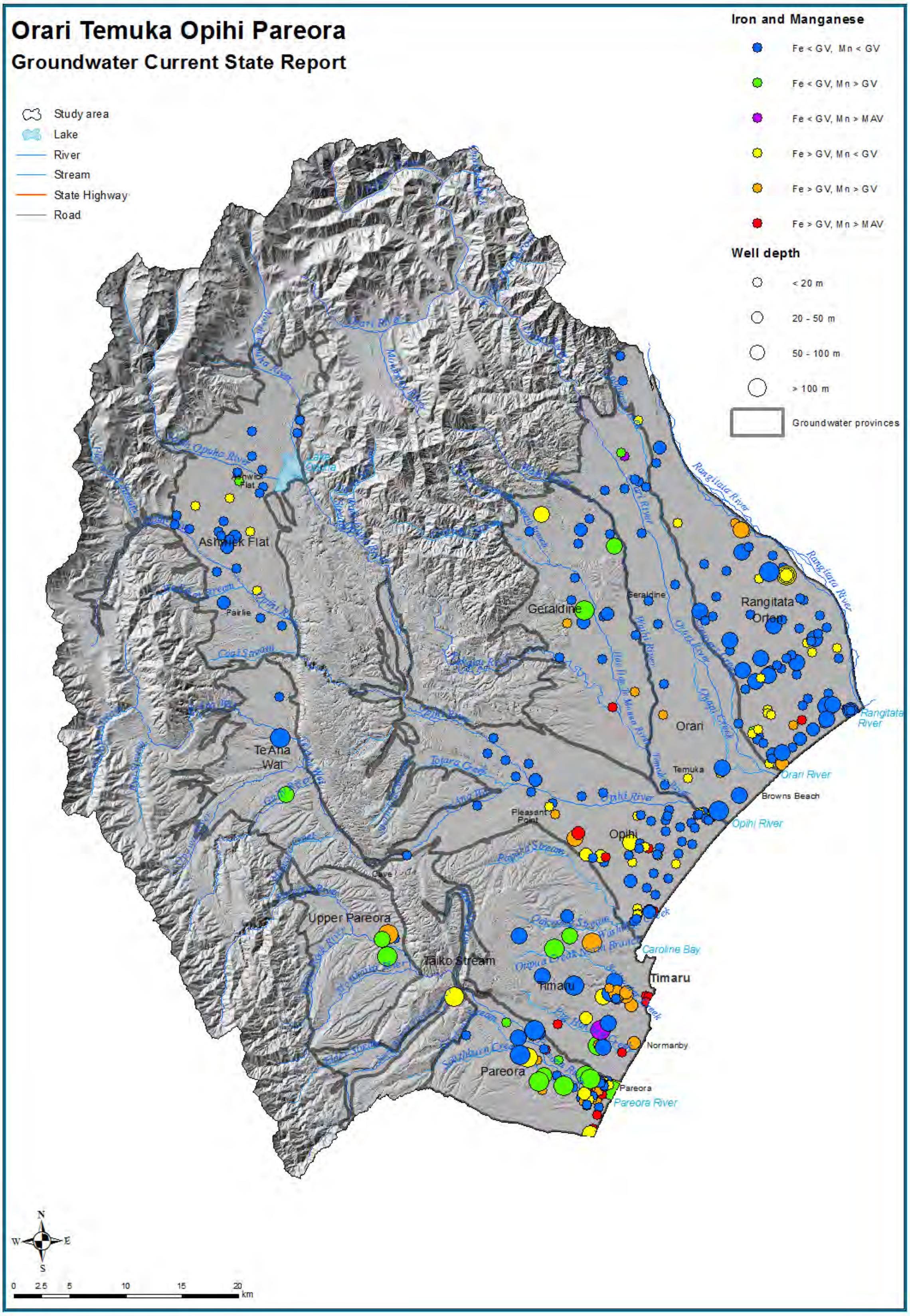

Figure 2-8: **Comparison of maximum iron and manganese concentrations (since 2000) with drinking-water thresholds (Ministry of Health, 2008)**

- **Opihi:** This province has low iron and manganese concentrations. Groundwater downgradient from the Seadown fertiliser storage has high iron and/or manganese concentrations. Areas of high concentrations in both shallow and deep groundwater are located near loess soils, Kowai Formation exposures, or Washdyke Lagoon. Groundwater from two shallow and one deep well has exceeded the MAV for manganese.

2.6.2 Inland Basins

Where there is low DO, iron and manganese concentrations increase, in cases above GV. Values here are lower than the Coastal Plains due to less contaminant and natural sources. By province:

- **Ashwick Flat:** Has low iron and manganese concentrations. Groundwater from one shallow well exceeded the GV for manganese on one occasion when DO was low. Groundwater from the other shallow well exceeded the GV for iron in one of 30 samples.

- **Te Ana Wai:** Has three wells whose groundwater has been tested for iron and manganese. Groundwater from one deep well exceeded the GV for manganese.

- **Upper Pareora:** Groundwater from one shallow well has low iron and manganese concentrations. Three deep wells have maximum manganese above the GV, one also has iron above the GV. Deep groundwater has low DO, and age dating indicates very old groundwater.

2.6.3 Downlands

The older groundwater of this province tends to be lower in DO meaning suitable conditions for iron and manganese to increase in concentration, over both GV and MAV. By province:

- **Taiko Stream:** No wells sampled.

- **South Branch Pareora:** Groundwater from one deep well has been sampled; its iron concentrations exceed the GV. This groundwater also has low DO concentrations and is over 43,000 years old.

- **Timaru:** Many deep wells tap groundwater with iron and/or manganese concentrations that exceed MAV. Not all deep wells have high iron concentrations, indicating a stratified groundwater system with different groundwater conditions and/or recharge sources. This is also reflected in variations of DO concentrations in deep groundwater and may indicate preferential pathways that allow fast, deep recharge. Some groundwater samples also exceed the GV for manganese and one the MAV.

- **Pareora:** Groundwater from many deep wells exceeds the GV for manganese, and some the GV for iron. Deep groundwater on the south bank is much younger than the north bank, but despite the faster recharge, conditions are suitable for DO to reduce and manganese concentrations to increase above MAV. Groundwater from most shallow wells exceeds GV for iron and/or manganese. This may be due to lower DO concentrations created by poorly drained soils and the presence of loess. Groundwater from two of the shallow wells also exceeds the MAV for manganese.

3 Suitability of groundwater for use

3.1 Groundwater use

Table 3-1 shows water use (based on primary use) for active and proposed wells in our study area from Environment Canterbury's Wells Database. The main uses of wells are for irrigation and for domestic and/or stock supply.

Table 3-1: Primary use for active and proposed wells

Well use	Number of wells
Commercial/Industrial	50
Dairy Use	47
Domestic and Stock water	265
Domestic Supply	536
Irrigation	1,087
Other	21
Public Water Supply	15
Small Community Supply	26
Stock Supply	99
Total	**2,146**

3.1.1 Drinking water wells

Currently, the greatest risk of groundwater supply contamination is from land use activities and discharges. Figure 3-1 shows the locations of active and proposed wells that are potentially used to supply drinking water to households and communities. There are 941 recorded drinking water wells (for human and stock) within the study area. Based on the observations of the Groundwater Field Team, only 10% of private wells have some form of water treatment installed (Ross Cressy, *pers. comm.*, 2017). Many household supplies from shallow private wells are therefore vulnerable to microbial contamination.

3.1.2 Public supply wells

As at November 2017 Environment Canterbury had record of 41 public/community supplies in the study area. Figure 3-2 shows the locations of these and their provisional source protection zones. The supply points include wells, galleries, springs, and surface water.

The largest population centre within the study area is Timaru. Its drinking water is sourced from surface water taken in the upper gorge of the Pareora River and from the Opihi River near Pleasant Point. The water is treated with ozone and chlorine to kill pathogens (Timaru District Council, 2017). There are various water supply schemes in other towns within the study area as well as smaller supplies such as schools, marae, parks, camps, cafes, and factories. Some of these supply water without any treatment.

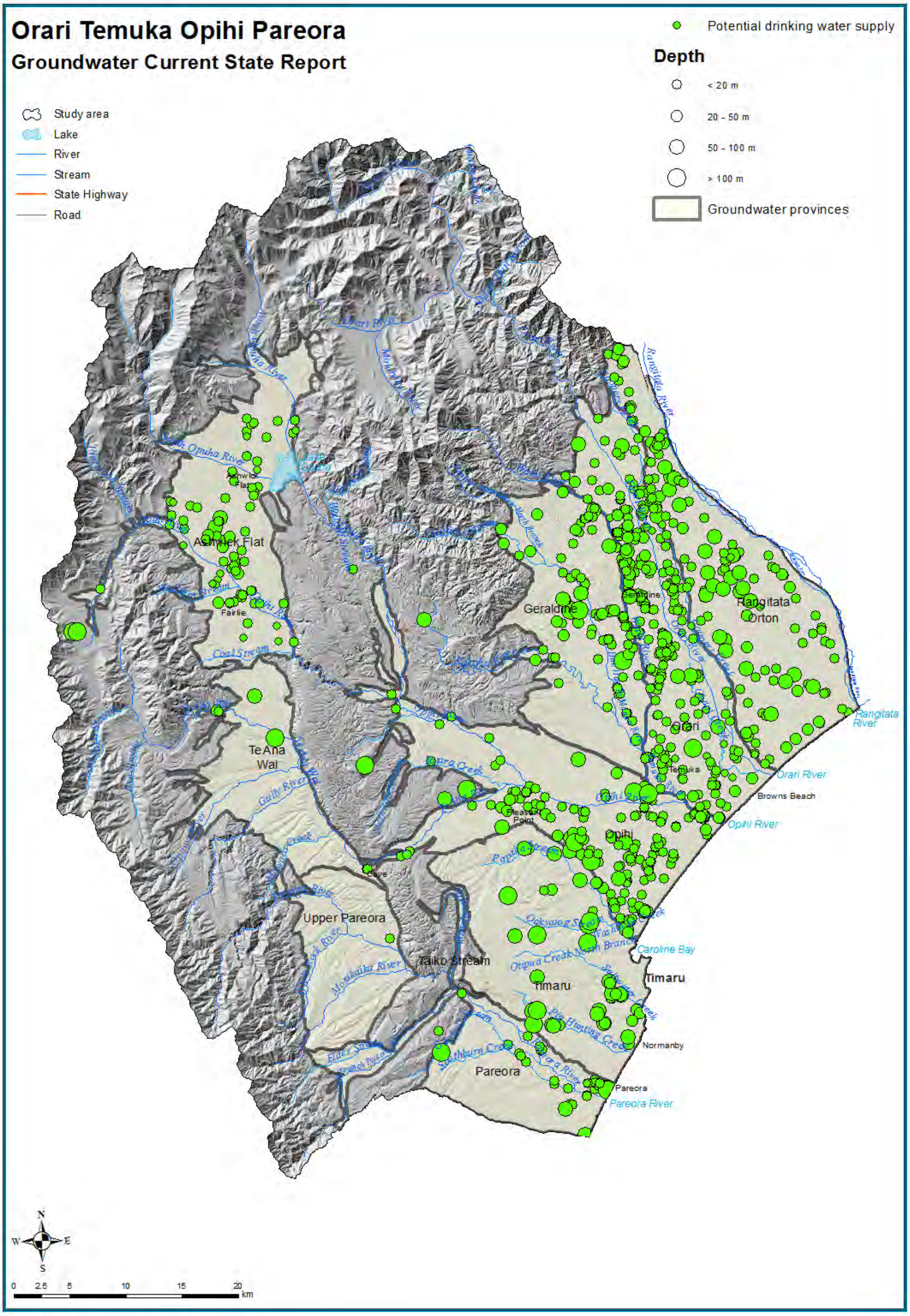

Figure 3-1: Locations of active and proposed wells potentially used to supply drinking water to households and communities. Size of dot indicates well depth

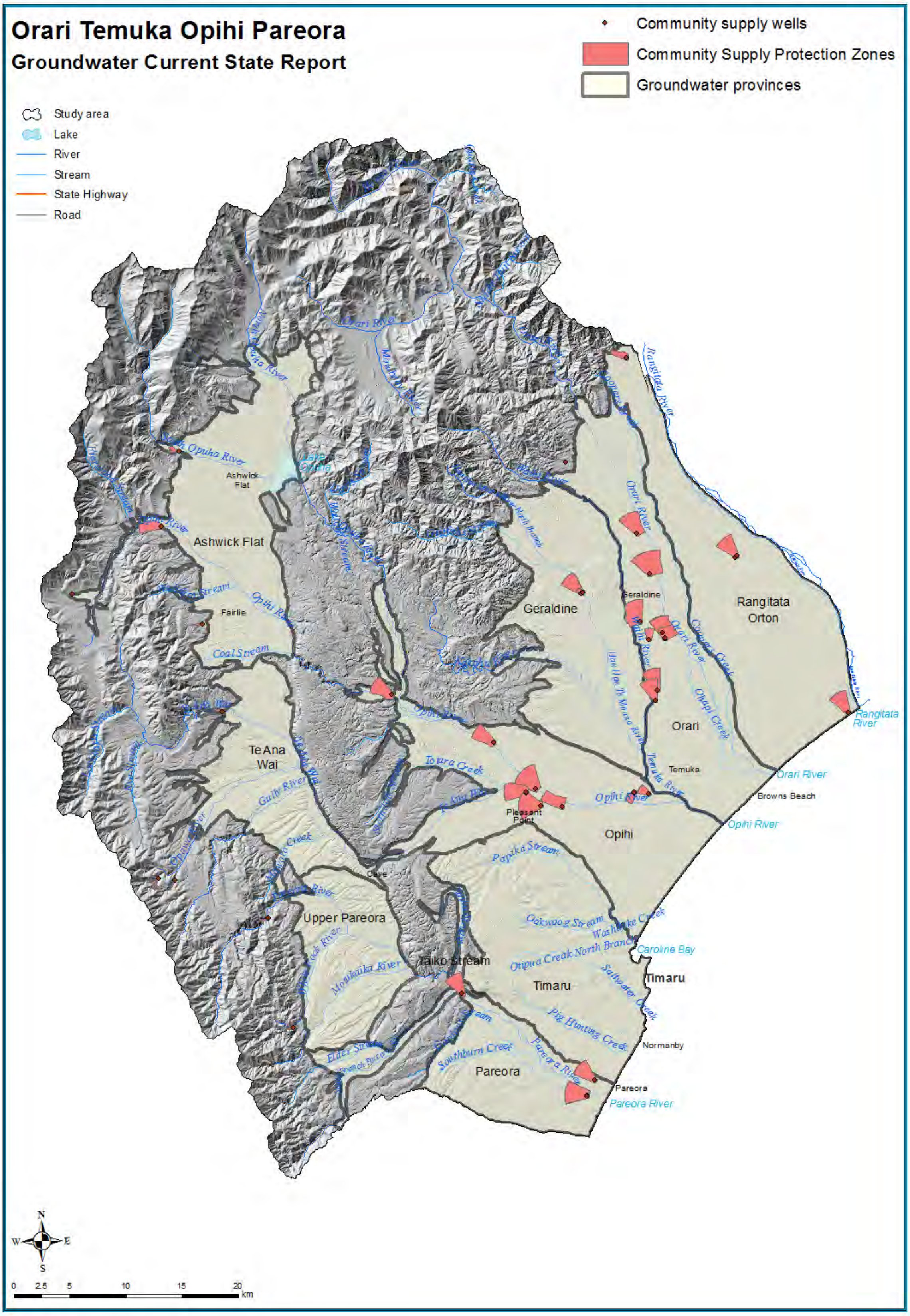

Figure 3-2: Locations of public water supply points (wells, galleries, springs, and surface water) and their provisional protection zones

3.2 Comparison with water quality guidelines and standards

The main guideline documents covering the most common groundwater uses in the study area are the New Zealand Drinking-Water Standards (NZDWS) (Ministry of Health, 2008) and the Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC, 2000). Appendix B lists the guideline values for parameters typically measured in groundwater for human consumption, stock water and irrigation water. In the NZDWS, MAVs are for parameters of health significance (e.g. toxic, carcinogen, etc.) whereas GVs are for parameters which have aesthetic effects (e.g. cause scaling, discolouration, taste or odour problems). These values can be exceeded due to naturally high concentrations or contamination from human activities. Appendix C lists wells that exceed these values, while Table 3-2 describes the exceedances.

Environment Canterbury stopped measuring for faecal coliforms in groundwater in the early 2000s and replaced it with *E. coli* measurements. *E. coli* is part of the faecal coliform count but is a more specific indicator of faecal contamination. Detection of *E. coli* indicates at least the same count as faecal coliforms. Wells with frequent detections of *E. coli* may require treatment to meet the drinking water standards. *E. coli* were detected in wells throughout the study area.

Low pH can result in plumbosolvency, where metals can dissolve from pipework. It is common in Canterbury for shallow groundwater to be slightly acidic, reflecting rainfall. In general, pH increases with groundwater depth and age, or due to wastewater discharges. A range of pH was set to limit corrosion and fouling of pumping, irrigation, and stock watering systems.

Environment Canterbury does not typically sample for Total Dissolved Solids but measures EC. Based on all Canterbury data, the approximate conversion between the two parameters is:

$$EC\ (mS/m) \times 5.95 = TDS\ (mg/L)$$

Localised contamination sources including the Seadown fertiliser storage facility, Clandeboye dairy factory, landfills, and wastewater systems, have caused localised instances of elevated ammonia, arsenic, hardness, nitrate-N, SO_4, and total dissolved solids. Nitrate-N also tends to exceed MAV in Levels Plain and Ashwick Flat. *E. coli* were present across the study area in concentrations exceeding GV, as were faecal coliforms in samples collected pre-2000. Manganese concentrations tend to be highest in the Timaru and Pareora provinces, while 15 wells (including some inland) exceed the GV for chloride. This suggests potential contamination from land uses, high impact of sea spray, or potential seawater intrusion. The Timaru province has consistently high concentrations of key analytes that are likely to impact or limit the uses of groundwater.

Table 3-2: Description of exceedances of water quality standards for each parameter

Parameter	Description of exceedances
Ammonia	7 wells exceed the NZDWS GV: two near Seadown fertiliser storage, one near Clandeboye dairy factory, one affected by an onsite wastewater system, and one near a landfill.
Arsenic	1 well near a landfill exceeds the MAV.
Chloride	15 wells exceed the GV. Exceedances are attributable to landfill leaching, sea spray, seawater intrusion, and the rest due to land use effects. 31 wells exceed the GV for irrigation of sensitive crops, nine exceed the GV for moderately sensitive crops, and four exceed the GV for moderately tolerant crops. Timaru province has naturally high chloride concentrations so groundwater may not be suitable for all uses.
E. coli	109 wells have *E. coli* detections (1980-2015); mainly shallow wells.
Faecal coliforms	25 wells exceed GV for stock water; 52 exceed GV for irrigation water for raw human food crops; 25 exceed GV for irrigation of pasture and fodder for dairy animals without a withholding period; six exceed GV for irrigation of pasture and fodder for dairy animals for a five day withholding period, or pasture and fodder for grazing animals except pigs and dairy animals, or raw human food crops not in direct contact with irrigation water or crops sold to consumers cooked or processed; one well exceeds GV for irrigation of silviculture, turf, cotton, etc. with restricted public access.
Hardness	39 wells exceed the GV: some near Clandeboye dairy factory and Seadown fertiliser storage; some near Washdyke Lagoon (potentially affected by seawater intrusion); some on Pareora River south bank (due to limestone geology); some in Timaru province (due to loess and basalt). 205 wells have elevated corrosion potential and 14 have increased fouling potential.
Iron	Since 2000, 36 wells have exceeded the GV: some in areas with naturally low DO concentrations (allowing release of iron), others in areas of depleted DO.
Manganese	Since 2000, nine wells have exceeded the MAV, 51 wells the GV for laundry use, and 29 wells the GV for taste. These occur where there is low DO, with the Timaru and Pareora provinces having the most exceedances. 14 wells exceed the long-term irrigation guideline, but none exceed the short-term guideline.
Nitrate-N	53 wells exceed the MAV: predominantly in areas dominated by LSR, near Clandeboye dairy factory, and Seadown fertiliser storage.
pH	293 wells were below the GV, and five above. 21 wells were below the irrigation GV and five above.
Sodium	Six wells exceed GV: three near a landfill, one near Washdyke Lagoon (likely seawater intrusion), one screened in the Taratu Formation (known to have high sodium concentrations). 18 wells exceed GV for irrigation of sensitive crops; six exceed GV for moderately sensitive crops; five exceed GV for moderately tolerant crops. Most exceedances are in Timaru province which has naturally high sodium sources so may not be suitable for all uses.
Sulphate	Three wells exceed GV: two near a landfill and one near Seadown fertiliser storage. One of the landfill wells also exceeds the stock water guideline.
Total Dissolved Solids	Eight wells exceed GV: three near landfill (also exceeds stock watering GV for poultry, dairy, cattle, horses, pigs; one also exceeds stock watering GV for sheep); one is coastal (may reflect seawater intrusion); one is screened in the Taratu Formation; one is close to a point source discharge; one is in Timaru province with high natural levels. 48 wells exceed GV for irrigation of sensitive crops; 15 exceed GV for moderately sensitive crops; four exceed GV for moderately tolerant crops; three exceed GV for tolerant and very tolerant crops. Most exceedances are in Timaru province which has naturally high concentrations so may not be suitable for all uses.

3.3 Seawater intrusion

Due to differences in densities, fresh water tends to float on top of seawater, creating an interface/wedge in coastal areas where groundwater discharges to the sea and seawater lies beneath. The location of the interface is determined by hydraulic gradient, thickness of the aquifer, and properties of the aquifer and aquitards that make up the groundwater system. The interface is not a sudden boundary but a diffuse transitional zone. Its location shifts due to natural variations in coastal discharge and groundwater levels. In areas with confining layers the interface may be different in different water bearing layers. The interface is further inland at greater depths, meaning that deeper wells near the coast are more likely to encounter the saline water.

Seawater intrusion is the movement of the freshwater/seawater interface inland from its natural state due to groundwater abstraction. In aquifers that underlie seawater, if pumping effects reduce the hydraulic pressure, downward migration of seawater can contaminate the aquifer. If seawater intrusion occurs, the groundwater may become unsuitable for its intended use.

Scott and Wilson (2012) previously identified parts of our study area as having some risk of seawater intrusion. Currently, there are five wells along the study area coastline to monitor seawater intrusion. The aim of this programme is to provide early indication of a landward shift of the freshwater/saline water interface.

Wilson and Graham (2014) reported that groundwater levels in the lower Kowai Formation south of Timaru are much lower than in the upper Kowai and the hydraulic gradient is much flatter. The groundwater levels are close to sea level even quite far inland. If the lower Kowai Formation connects with the coast, the seawater interface may be present quite far inland. Over-abstraction of this aquifer could result landward migration of the interface and localised seawater intrusion.

Environment Canterbury performs groundwater quality monitoring for seawater intrusion twice a year, once during the spring annual survey, and once in autumn (March or April) towards the end of the irrigation season. While conductivity alone is usually enough to indicate seawater intrusion, other parameters are useful in excluding other reasons for high conductivity such as natural geology or point source contamination. Currently, seawater intrusion does not appear to be a major problem along the coastline, but it may be an issue in isolated areas.

From the high conductivity data, the area near Washdyke may be prone to seawater intrusion, particularly in shallow groundwater. A deep seawater intrusion monitoring well just north of St Andrews (J39/0532) shows slightly higher conductivity and chloride concentrations at the end of the irrigation season, and a deep well near the Pareora River (J39/0009) is showing an increasing trend in these parameters (Appendix D).

4 Land use effects

4.1 Types of contaminants

Broadly speaking, contaminants can either be diffuse or from point sources. In diffuse pollution, contaminants enter groundwater over a large area, while point source discharges are from a discrete location. Contaminants increase concentrations of chemicals in groundwater above natural levels, but typically we only concern ourselves with contaminants that have heath impacts or change the aesthetic properties of groundwater. Where groundwater discharges into surface waters, we also consider contaminants that may negatively affect surface water quality (e.g. phosphorus). Human activities that result in a change in the redox state of groundwater (i.e. reducing conditions) can also make some analytes more soluble, increasing their concentrations in groundwater. We discuss exceedances of guideline values in Section 3.2 and some of their natural or human sources. The three main groundwater contaminants that pose a risk to human health or the environment are nitrogen, phosphorus and *E. coli*.

4.2 Diffuse pollution

Normal agricultural activities such as animal grazing, fertiliser application, and effluent disposal are sources of diffuse pollution. Urban areas are also sources of various diffuse contaminants from roads, houses, gardens, commercial, and industrial activities. Timaru is the largest urban area within our study area. Other significant towns are Temuka, Geraldine, Pleasant Point and Fairlie. Figure 1-2 in Section 1.4 shows the land use types.

Controls on diffuse discharges from farming are new in Canterbury. The limit-setting process for the OTOP zone involves working with the community to develop solutions for managing diffuse nutrients from farming.

4.3 Point source discharges

Wastewater treatment plants, landfills, effluent storage tanks, onsite wastewater systems, and industrial activities are examples of point source discharges of contaminants. Figure 4-1 shows the locations of point discharges that are likely to contribute nutrients to groundwater within the study area.

There are large numbers of dairy effluent discharge consents within the Rangitata-Orton, Orari and Geraldine provinces. Each dairy farm is likely to have an effluent pond, as are piggeries. These ponds would leak some nutrients to groundwater. Loe and Clarke (2017) estimate 183 farm effluent ponds in the OTOP area.

There are six community wastewater treatment plants within the study area which service Fairlie, Timaru, Burkes Pass, Geraldine, Temuka and Pleasant Point. There is also a treatment system at Clandeboye for the dairy factory and hall. Households in areas not connected to community wastewater rely on individual onsite wastewater systems. Figure 4-1 does not show all onsite wastewater systems as some of the systems were installed as a permitted activity. Loe and Clarke (2017) estimate there are 3,890 onsite wastewater systems within the study area.

There are also food or milk processing companies with active wastewater discharge consents that contribute nutrients to groundwater. The largest industry is the dairy factory at Clandeboye. The factory discharges wastewater to land across the lower Rangitata-Orari plain. These discharges contribute to very high nitrate-N concentrations in groundwater (Scott, *et al.,* 2011). In 2007, Fonterra obtained a consent to discharge their process wastewater and condensate via an ocean outfall. However, as the region is under pressure for freshwater resources, particularly in the summer months, Fonterra still irrigates wastewater when required for farm production.

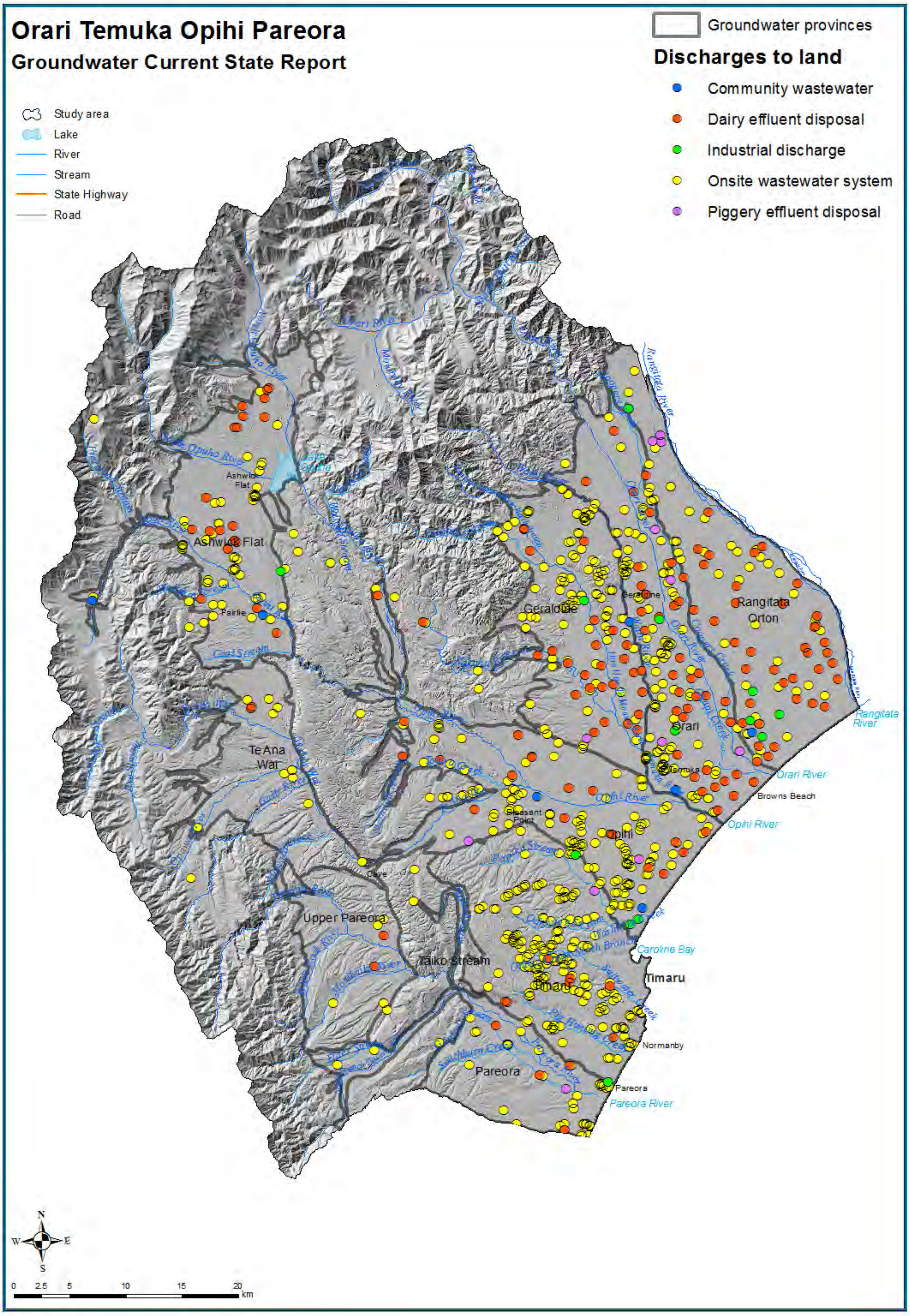

Figure 4-1: Locations of discharges that could contribute nutrients to groundwater

The meat processing plant in the Pareora province, near the Pareora township and north of the Pareora River, is another significant contributor of nutrients. The plant discharges some of its wastewater to land. Because of its location near the coast, there are no downgradient groundwater users and the only effects are on the processing plant drinking water well and on the lower Pareora River. There are a few other food processing discharges across our study area.

Seadown fertiliser storage facility near Seadown (in the Opihi province) discharges wash-down water and storm water as either irrigation or directly to a soak pit when their storage pond is full. A plume of contaminants extends downgradient from the site towards the coast.

4.4 Nitrogen

4.4.1 Sources and transport

Nitrogen is an important nutrient for plants and animals. Nitrogen is applied as a fertiliser (e.g. urea) on land to improve plant growth, but can also be a cause of unwanted growth of plants and algae in waterways. Nitrogen is present in decaying organic matter in soils and in human and animal excreta discharged into or onto the land. Nitrogen from fertiliser or effluent can be converted to nitrate in soil. Nitrate is soluble in water and prone to leaching to groundwater.

The nitrate molecule contains nitrogen, and typically, Environment Canterbury reports nitrate concentrations in terms of nitrate-nitrogen (nitrate-N). Nitrate is the fully oxidised and most stable form of dissolved nitrogen in water, but it can be converted to other nitrogen compounds. Reporting nitrate as nitrate-N is useful because nitrate can be biologically converted to other nitrogen compounds (such as organic nitrogen, ammonia, or nitrite). In all conversions the amount of nitrogen stays the same unless it is removed from the system.

4.4.2 Why we care about nitrate-N concentrations

Increasing the extent and/or intensity of agricultural land use increases nitrate-N concentrations in groundwater. Increasing nitrate-N concentrations are of concern because

- nitrogen is a plant nutrient, so it contributes to nuisance periphyton and macrophyte growth in streams/rivers which can alter water quality to a point that it stresses ecological values
- nitrogen is a factor in the growth of toxic cyanobacteria in waterways. Toxins from cyanobacterial blooms are harmful to human and animal health
- high concentrations of nitrate-N in drinking water can be harmful to human health. The NZDWS (Ministry of Health, 2008) set a short-term MAV for nitrate-N at 11.3 mg/L (equivalent to 50 mg/L of nitrate), based on a risk to bottle-fed babies
- nitrate-N can be toxic for aquatic life in groundwater and groundwater-fed streams/rivers, and can have chronic effects on aquatic life. The National Policy Statement for Freshwater Management (Ministry for the Environment, 2014) set a National Bottom Line for nitrate-N toxicity in rivers of 6.9 mg/L annual median, and 9.8 mg/L annual 95th percentile nitrate-N.

4.4.3 Nitrate-N leaching risk

Figure 4-2 shows the nitrate-N leaching risk determined by Webb, *et al.* (2010). This risk is based on soil types and their likelihood to provide conditions suitable for denitrification. Soils with a very high risk will leach more nitrate-N than soils with a very low risk. The map only covers the flatter areas of the Canterbury region, and therefore excludes part of the study area. Because the areas excluded are largely hill country, their steepness is likely to result in runoff, with only the flatter areas expected to have significant leaching to groundwater.

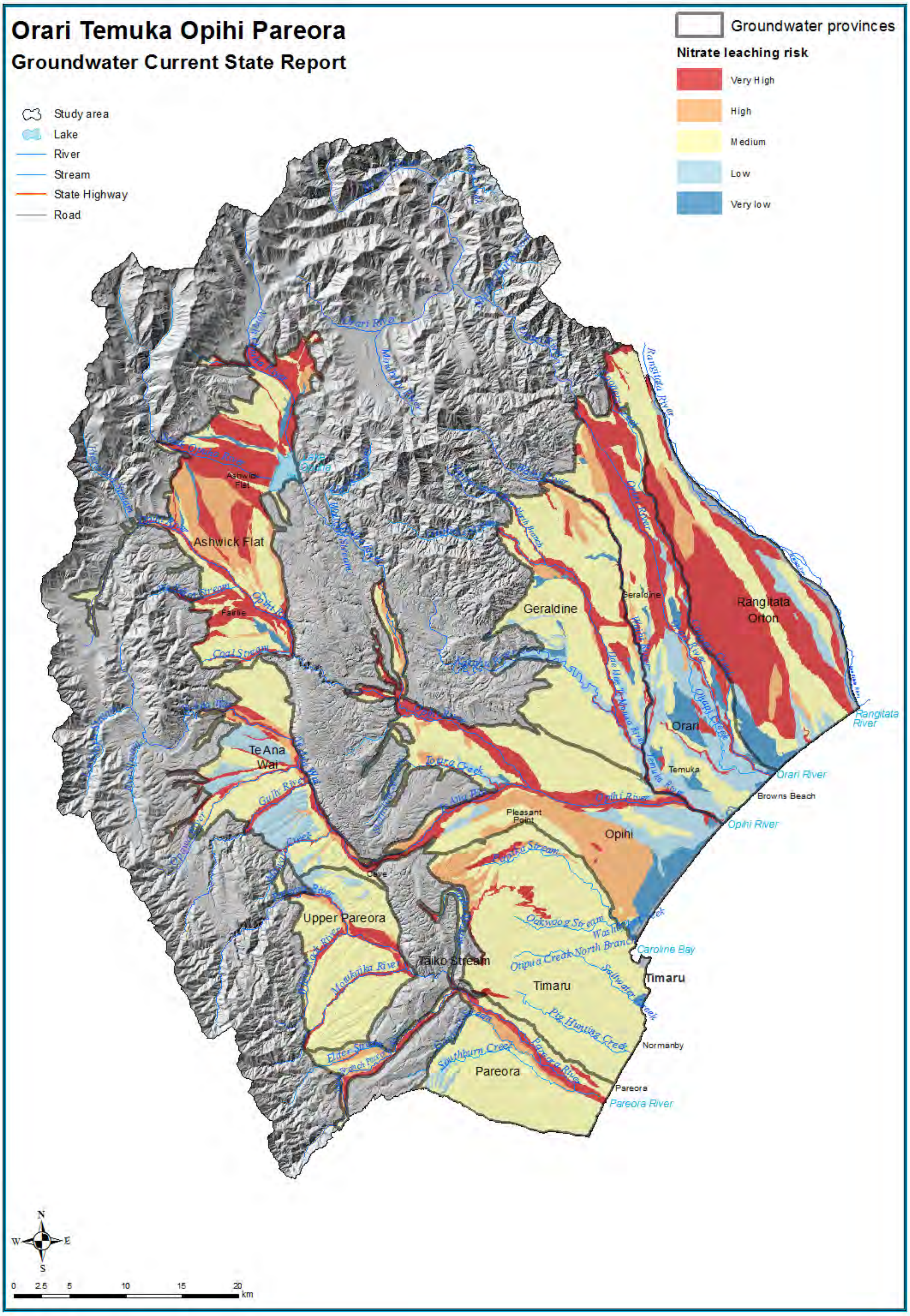

Figure 4-2: **Nitrate-N leaching risk as determined by Webb, *et al.* (2010)**

Areas immediately adjacent to rivers often have very high risk of leaching, as the soils are shallow and stony with limited water holding capacity. The Rangitata-Orton and Ashwick Flat provinces have extensive areas with high or very high nitrate-N leaching risk. This aligns with groundwater monitoring results in these areas.

It is important to note that the risk map does not always align with the nitrate-N concentrations measured in groundwater. For example, some areas of high leaching risk do not have intensive land uses so will have low nitrate-N concentrations. Rivers or water races may provide recharge and dilution, therefore the concentrations measured will be lower in those areas. The map does not give information on deep groundwater and will not account for areas where denitrification is occurring. Areas of low leaching risk can also have higher nitrate-N concentrations than expected. Nitrate-N can travel long distances in groundwater, so nitrate-N concentrations seen in a well may be from upgradient land uses on different soils. The map also does not account for bypass flow which can cause rapid deep drainage even in areas of low leaching risk. The risk map shows the potential for nitrogen leaching from land but the corresponding effect on groundwater will depend on the physical characteristics of the groundwater system and other inputs (e.g. leakage from water races). Differences between measured concentrations and the risk category can be used to identify areas for investigation.

4.4.4 Nitrate-N concentrations in groundwater

Nitrate-N occurs naturally in groundwater, but generally at concentrations less than 1 to 3 mg/L nitrate-N (Close, *et al.,* 2001; Chapelle, 1993; Madison & Brunett, 1985 in Hanson, 2002). Recent analysis carried out by Morgenstern and Daughney (2012) shows that most natural concentrations of nitrate-N in New Zealand groundwater are likely to be below 0.25 mg/L. Based on correlations between groundwater age estimates and nitrate-N concentrations Morgenstern and Daughney found

- nitrate-N concentrations between 0.2 and 2.5 mg/L tend to indicate low intensity impacts from about the 1880s onwards; and
- nitrate-N concentrations above 2.5 mg/L generally occur in groundwater recharged after the 1950s, when land use began to intensify.

Figure 4-3 shows the highest nitrate-N concentrations ever recorded in each well, and irrigated areas. Showing maximum concentrations emphasises areas where concentrations have always been low. Areas with low nitrate-N concentrations indicate that the groundwater is derived primarily from surface water recharge, land with low nitrate-N leaching concentrations, conditions suitable for denitrification, or a combination of these factors.

LSR carries nitrate-N down into groundwater, with more intensive land use often resulting in higher nitrate-N concentrations. Nitrate-N travels with the groundwater until it discharges in spring-fed streams, rivers, or offshore. The concentration in discharged water reflects groundwater at the water table. Nitrate-N concentrations only decrease if they are diluted through mixing with water of lower nitrate-N concentrations, or if denitrification occurs. Nitrate-N leaching from the surface and shallow groundwater takes time to move down to the deeper parts of an aquifer. Nitrate-N concentrations are highest near the water table. From Figure 4-3 it is clear there are extensive areas with nitrate-N concentrations in shallow groundwater elevated above natural concentrations.

Coastal Plains

Much of this environment is under intensive land use. Where LSR is the dominant recharge source nitrate-N concentrations tend to be higher, except on poorly drained soils and where groundwater has low DO. Elevated nitrate-N concentrations occur in deep groundwater in areas dominated by LSR. Areas dominated by river recharge have lower nitrate-N concentrations.

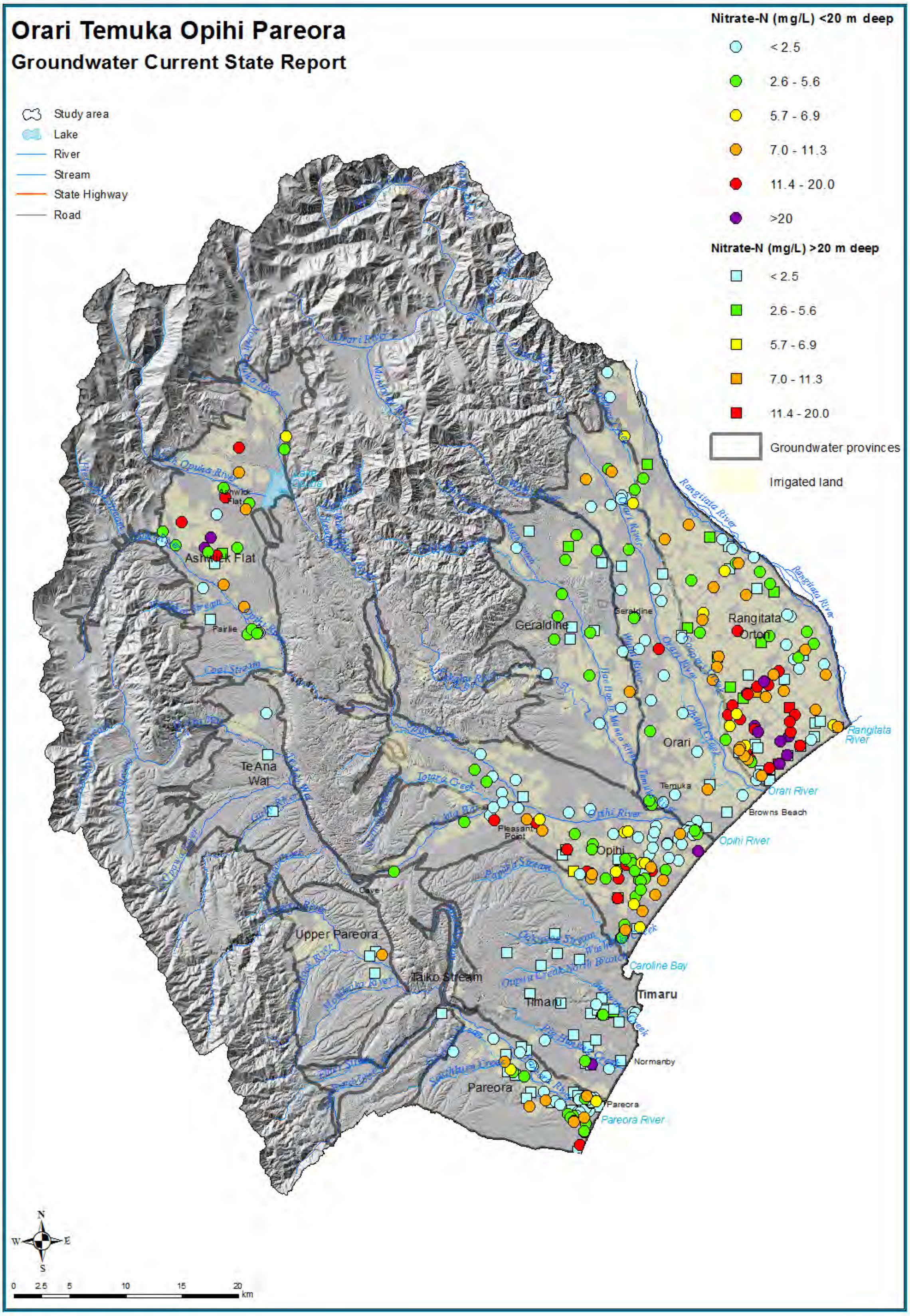

Figure 4-3: Maximum nitrate-N concentrations ever recorded in shallow and deep wells

By province:

- **Rangitata-Orton:** Scott, *et al.* (2011) link nitrate-N contamination near Clandeboye to wastewater discharges from the dairy factory. They also note contamination in some deeper wells. Scott, *et al.* (2011) identify an area downgradient of the factory wastewater discharge as having low DO and some denitrification could be occurring. Wells upgradient from Clandeboye have elevated nitrate-N concentrations as the area has light soils, many dairy farms, and LSR dominates. Near the Rangitata River nitrate-N concentrations are lower despite similarly intensive land use as river recharge dilutes leachate. Deeper wells near the coast have lower nitrate-N concentrations than further upgradient. Here, DO concentrations are too high for denitrification to occur, so these wells could be tapping older groundwater which pre-dates intensive land use. Near lower Orari, denitrification may be occurring in shallow groundwater as nitrate-N concentrations are low, as is DO, and there are poorly-drained soils.

- **Orari:** Orari River recharge dominates the province. Only one well in the province has nitrate-N concentrations above the MAV. This well may be affected by a point source discharge rather than representing a larger area of poor groundwater quality. Groundwater from one shallow well near the lower part of the province and one near the western inland area exceed half MAV. These are in areas dominated by LSR. Deep groundwater has low nitrate-N concentrations; less than 2 mg/L.

- **Geraldine:** Has no wells that exceed the MAV. The southern part of the province has intensive land use. However, this occurs on poorly drained areas with low DO groundwater, indicating that there could be less leaching or that the conditions are suitable for denitrification. The northern part of this province has less irrigated land (i.e. less intensive land use) and so lower nitrate-N concentrations. One of the deeper wells in the northern part of the province had a nitrate-N concentration of 2.6 mg/L so is likely recharged by LSR. All other deep wells have concentrations below 1 mg/L.

- **Opihi:** Smith (1993b) found a small area where the Seadown fertiliser store caused nitrate-N contamination. Other shallow wells also have nitrate-N concentrations above the MAV. This is likely to be due to extensive cropping and/or dairy farming, combined with light soils prone to leaching. The areas dominated by Opihi River recharge (as indicated by $\delta^{18}O$) generally have lower nitrate-N concentrations. Some of the deeper wells, in areas dominated by LSR, have elevated nitrate-N concentrations indicating that nutrients can travel reasonably fast into the deeper aquifers.

Inland Basins
Where samples are taken from shallow groundwater near an irrigated area, nitrate-N concentrations tend to be elevated and can exceed MAV. Deep groundwater appears unaffected by land use. By province:

- **Ashwick Flat:** The Ashwick Flat province has some wells that exceed the nitrate-N MAV, particularly in irrigated areas and where there is cropping or dairy farming. Additionally, the soils are light and therefore prone to nitrate-N leaching; DO is high so denitrification is unlikely. Based on the high nitrate-N concentrations, LSR appears to dominate the area. Two deeper wells both have concentrations below 2.5 mg/L.

- **Te Ana Wai:** Three wells have been sampled; two deep and one shallow. The two deep wells had low nitrate-N concentrations, while the shallow well was at the upper limit of background levels.

- **Upper Pareora:** Four wells have been sampled. The three deep wells have low nitrate-N concentrations (below 2.5 mg/L), while the shallow well has high concentrations that are approaching the MAV. The shallow well is near an irrigated dairy farm and on light soils, which is thought to be the primary source.

Downlands
Generally, nitrate-N concentrations in both shallow and deep groundwater are low. Exceedances are likely caused by point source contamination with possible ionic influence. By province:

- **Taiko Stream:** No wells sampled.

- **South Branch Pareora:** One deep well has very old groundwater with nitrate-N concentrations within the background range.

- **Timaru:** One shallow well exceeds the MAV for nitrate-N. The 10 other shallow wells have low to mid-range concentrations. Some of the deeper wells have low concentrations while others have concentrations above what we consider natural and up to 3 mg/L. Wells in the Timaru province have a mix of low and high DO concentrations. Many deep wells have high DO concentrations so denitrification is unlikely. There is no evident relationship between high DO and high nitrate-N in this province.

- **Pareora:** Nitrate-N concentrations are higher on the south side of the Pareora River than the north side. This is likely due to anthropogenic effects and some LSR influence. We infer rapid recharge to deep groundwater on the south side, as some deep wells have nitrate-N concentrations above background levels. The loess soils on the south side of the river have a high risk of bypass flow or lateral drainage allowing rapid movement of LSR to the connected river gravels in the Pareora valley. The north side receives more river recharge and therefore nitrate-N concentrations are lower. The deep groundwater on the north side has low nitrate-N concentrations, and this groundwater is very old. There is one shallow well near the coast where the maximum nitrate-N concentration has exceeded the MAV. This well also had high faecal coliform count, indicating contamination from effluent.

4.4.5 Estimating nitrate-N concentrations based on the Matrix of Good Management

Figure 4-4 shows nitrate-N concentrations in recharge based on outputs (Mojsilovic, *pers. comm.*) generated from the Matrix of Good Management (MGM). The MGM combines soil, climate, and land use information to estimate nitrogen leaching losses under good farm management for different land use types. We assume recharge has the same nitrate-N concentrations as the MGM estimate for leaching below the root zone (Table 4-1). On average, only the Rangitata-Orton province has nitrate-N recharge concentrations that do not meet the MAV. Our understanding is that the MGM assumes some good management practices, which may not be representative of current farming practices. Therefore, estimated concentrations may be different from actual concentrations.

All provinces have some areas where recharge concentrations are predicted to exceed the MAV. Rangitata-Orton province has the largest area but Orari, Geraldine, Opihi and Ashwick Flat also have significant areas that exceed the MAV. Of those, parts of Rangitata-Orton, Ashwick Flat and Opihi provinces are dominated by LSR and were previously identified as target areas for focused reductions in nitrate-N leaching (Scott, 2017). Areas of intensive land use have high nitrate-N concentrations. Some areas receive additional river recharge (and/or denitrification occurs) that may result in measured nitrate-N concentrations being lower than the modelled values.

Figure 4-4 also shows “high concentration areas” as defined by Scott and Hayward (2017) because: modelled nitrate-N leaching concentrations were high; these areas are dominated by LSR; measured nitrate-N concentrations in groundwater were high and do not meet the MAV in some areas; groundwater is potentially used for drinking-water, and; groundwater-fed surface waters were not meeting some targets.

The average measured nitrate-N concentrations in the Rangitata-Orton “high concentration area” are above half MAV. This area has many wells potentially used to supply drinking water and one public supply well near Rangitata Huts. McKinnons Creek, also fed by groundwater from near the Rangitata River, has high nitrate-N concentrations. It may be “skimming off” groundwater near the water table, which has the highest nitrate-N concentrations. This creek does not meet the national bottom line for nitrate toxicity (Hayward, *et al.,* 2016). Groundwater-fed Rhodes Stream, at Clandeboye has nitrate-N concentrations that do not meet the national bottom line (6.9 mg/L).

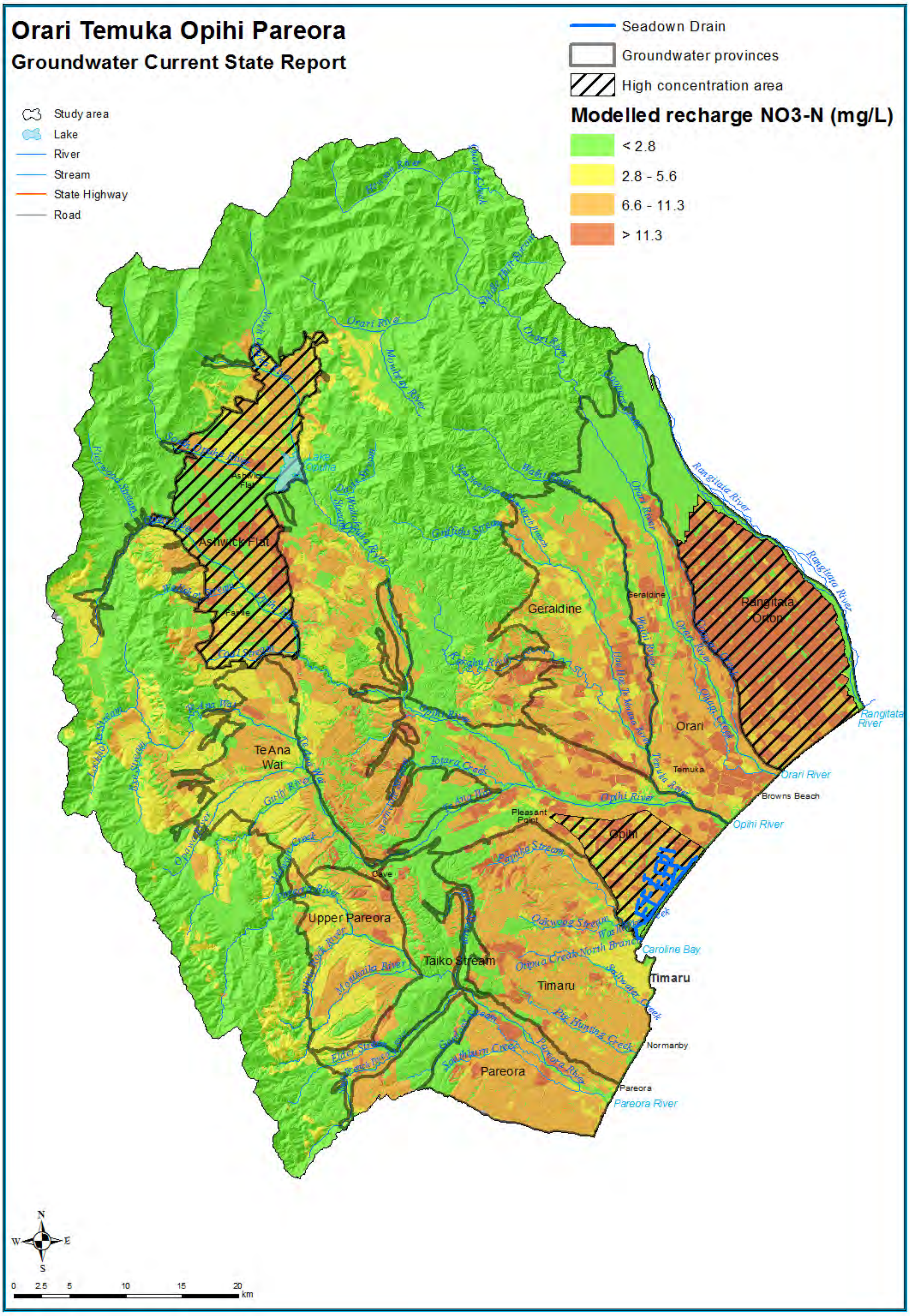

Figure 4-4: **Modelled nitrate-N concentrations in recharge (Mojsilovic, *pers. comm.*) and high concentration areas based on measured values**

Table 4-1: Estimated nitrate-N recharge concentrations

Province	Concentration (mg/L)
Ashwick Flat	6.2
Geraldine	6.2
Opihi	8.3
Orari	8.0
Pareora	8.6
Rangitata - Orton	12.0
South Branch Pareora	5.4
Taiko Stream	6.4
Te Ana Wai	5.3
Timaru	7.9
Upper Pareora	5.7

The average measured nitrate-N concentrations in the Ashwick Flat "high concentration area" are above half MAV. There are many wells potentially used to supply drinking water. The area also has increasing nitrate-N trends in groundwater. This groundwater drains either to the Opuha River or upper Opihi River above the gorge. There are increasing nitrate-N+nitrite-N concentrations in the North Opuha River, Opuha River below Lake Opuha, and the Opihi River at Rockwood (immediately downstream of the gorge) (Hayward, *et al.,* 2016). The Opihi River mainstem exhibits increasing levels of nuisance periphyton cover at downstream sites (especially at Grassy Banks), but can have high cover at upstream sites in years with low and stable flows. The lower Opihi River suffers from frequent blooms of potentially toxic benthic cyanobacteria (phormidium), often rendering sites unsuitable for recreation (Hayward, *et al.,* 2016). There is concern that increases in nitrogen concentrations in the upper Opihi River may result in more extensive and frequent phormidium blooms. (Hayward, 2017)

The average measured nitrate-N concentrations in the Levels Plain "high concentration area" are above half MAV. There are many wells potentially used to supply drinking water. Groundwater from this area flows towards Seadown Drain that runs along the coast, and on towards Washdyke Lagoon. Seadown Drain contributes most of the fresh water in the Lagoon. Washdyke Lagoon does not meet the national bottom line for total nitrogen and total phosphorus (Scott & Hayward, 2017).

4.4.6 Trends in nitrate-N concentrations in groundwater

Environment Canterbury samples groundwater on a regular basis to monitor trends over time. As described in Section 1.7, there are 46 wells (Figure 1-5) that are part of long-term monitoring programmes. Appendix E shows the nitrate-N trends from wells in Environment Canterbury monitoring programmes. Some wells have been monitored since 1991, with others added later to fill spatial gaps. Monitoring frequencies have also changed (increased or decreased) for some wells. More frequent monitoring sometimes causes 'spikes' in the long-term monitoring trends as more recharge events are observed. Most (71%) of our long-term monitoring wells do not show increasing or decreasing long-term trends for nitrate-N. Increasing trends are seen in

- one shallow well in the Opihi province and one shallow well in the Orari province
- the Ashwick Flat area, presumably due to land use intensification
- one shallow well in the Timaru province
- two shallow wells in the Pareora province. Water in one well has been dated at around 30 years, so this may be historical land use change effects
- some deep wells in the lower Rangitata-Orton province and on the Levels Plain that are likely to be lagged land use effects. Based on age dating data, the lag in the deeper wells may be around 20 to 40 years in the Rangitata-Orton province

and decreasing trends in

- shallow groundwater near the RSIS distribution races, likely due to dilution from leaky water races
- one shallow well in the Opihi province.

4.5 Phosphorus

4.5.1 Sources and transport

Phosphorus is a plant nutrient applied as fertiliser to improve plant growth. Its effect in surface water is like nitrate-N; increasing concentrations can result in excess plant growth and lead to eutrophication. There are no health-based limits set for phosphorus; the main concerns are environmental.

Phosphorus is measured in many forms, including total phosphorus (which includes particulate phosphorus), dissolved reactive phosphorus (DRP) and soluble unreactive phosphorus. For groundwater, we are particularly interested in DRP that is readily available for plant growth.

In New Zealand, the most common source of phosphorus is from fertiliser used in agricultural areas (Rosen, 2001). Effluent is also very high in phosphorus; effluent discharges to land will increase phosphorus in soil. Phosphorus can occur naturally in groundwater where present in rocks and soils. Apatite (a calcium phosphate mineral) in rocks and soils may be a source of phosphate in groundwater (Rosen, 2001) but it is only slightly soluble. Therefore, long residence times and long travel paths are needed to increase DRP concentrations. High DRP concentrations in deep groundwater are likely to be from natural sources.

Although the phosphate ion, like the nitrate ion, is negatively charged, it interacts differently with soil. It adsorbs onto the soil particles and the phosphorus becomes immobile. Elevated levels of calcium, iron, or aluminium can reduce phosphorus solubility. Phosphorus loss is associated with runoff, where it is carried as part of sediment into surface waters. Phosphorus can desorb from sediment under certain conditions, and result in nuisance macrophyte and periphyton growth in rivers and streams.

While the main loss of phosphorus is via runoff, recent research has shown that phosphorus can leach through the soil if applied in excess of the soil's retention capacity (Reading, *et al.,* 2006), which depends on soil type and factors that affect soil sorption. Hesketh and Brookes (2000) show that a build-up of excess phosphorus in soil over time will eventually lead to leaching into groundwater.

McDowell, *et al.* (2014) explore linkages between soil, surface water, and groundwater enrichment with phosphorus. They show that soil was especially enriched with phosphorus under dairying with high cow numbers and high phosphorus-fertiliser use. They conclude that groundwater could contribute significant phosphorus to connected surface waters on soils prone to leaching and with intensive land use.

Scott and Wong (2016) found that phosphorus concentrations from both natural and man-made sources are linked to the redox state of groundwater. Most of Canterbury's groundwater is oxidised (has high DO). Phosphorus mobility is limited in this environment. If there is a source of phosphorus contamination, DRP is more likely to reach high concentrations if the groundwater is or becomes reduced. This behaviour is broadly the inverse of nitrate-N, so we often see elevated DRP in areas where nitrate-N concentrations are low.

4.5.2 Why we care about its concentration in groundwater

Increasing the extent and/or intensity of agricultural land use may increase phosphorus concentrations in groundwater and surface water. Increasing phosphorus concentrations are of concern because it contributes to nuisance periphyton and macrophyte growth in streams/rivers, and associated deterioration of water quality (e.g. DO and pH) can stress ecological values. Phosphorus is also a factor in the growth of toxic cyanobacteria in waterways. Increasing phosphorus concentrations increases the opportunity for cyanobacterial blooms.

4.5.3 Leaching risk

Figure 4-5 shows the phosphorus leaching risk determined by Webb, *et al.* (2010). This risk is based on a combination of phosphorus retention and effective thickness of fine soil material on a whole-profile basis. Soils with a very high risk will leach more phosphorus than soils with a very low risk. Areas adjacent to rivers often have very high risk of leaching as they are shallow and stony. The map only covers the flatter areas and not hilly areas, and therefore part of the study area is not covered. However, most of the groundwater environments and provinces are covered. The areas not covered by the risk map are steep and are more likely to result in runoff rather than leaching to groundwater.

The Rangitata-Orton and Ashwick Flat provinces have extensive areas with low phosphorus leaching risk. This generally agrees with groundwater monitoring results. However, it is important to note that risk maps do not always agree with the concentrations measured in groundwater. Some areas of high leaching risk do not have intensive land uses so will have low phosphorus concentrations. Rivers or water races may provide recharge and dilution, therefore the concentrations measured will be lower. The map does not give information on deep groundwater, where phosphorus can be slowly dissolved from geological sources. Areas of low leaching can also have higher phosphorus concentrations than expected due to poor management, point source discharges, or geology. The risk map also does not account for bypass flow, which can cause rapid deep drainage even in areas of low leaching risk.

Figure 4-6 shows the bypass-flow risk determined by Webb, *et al.* (2010). This is based on soil classification, structure, and attributes. High-bypass-flow soils can transmit significant amounts of water through macropore flow compared with flow through the fine pores of the soil matrix. Soils with a very high bypass risk will leach more phosphorus than soils with a very low risk. The Coastal Plains has large areas with elevated risk of bypass-flow. Medium- to high-bypass-flow soils occur on the Downlands where areas have moderately structured upper subsoils, but impermeable deeper subsoils (fragipans). These soils have moderate preferential flow down to the fragipan where water is then perched; has minimal deep percolation meaning phosphorus (and other contaminants) will be detained and attenuated within the landscape. If these soils are drained, the drains provide a pathway for rapid phosphorus transport into streams.

4.5.4 DRP concentrations in groundwater

Figure 4-7 shows the highest DRP concentrations ever recorded in each well in the study area. Highest concentrations are from groundwater in wells near point sources and old anoxic groundwater in deep wells. Groundwater from some shallow wells could naturally have high DRP concentrations due to local geology or from upwelling of older groundwater.

There are no drinking-water limits for DRP, so we have adopted surface water quality thresholds to classify the data. The New Zealand Periphyton Guideline (Ministry for the Environment, 2000) has DRP GVs that protect aesthetic/recreational values against excessive periphyton biomass. These recommend DRP concentrations for 20 days of accrual[4] of 0.026 mg/L and 30+ days of accrual of 0.006 mg/L. There is also a GV for the protection of biodiversity (0.001 mg/L) but most values for all river types in Canterbury are above this value (Stevenson, *et al.,* 2010).

[4] Days of accrual are the number of days since the last flushing flow that will remove periphyton growth.

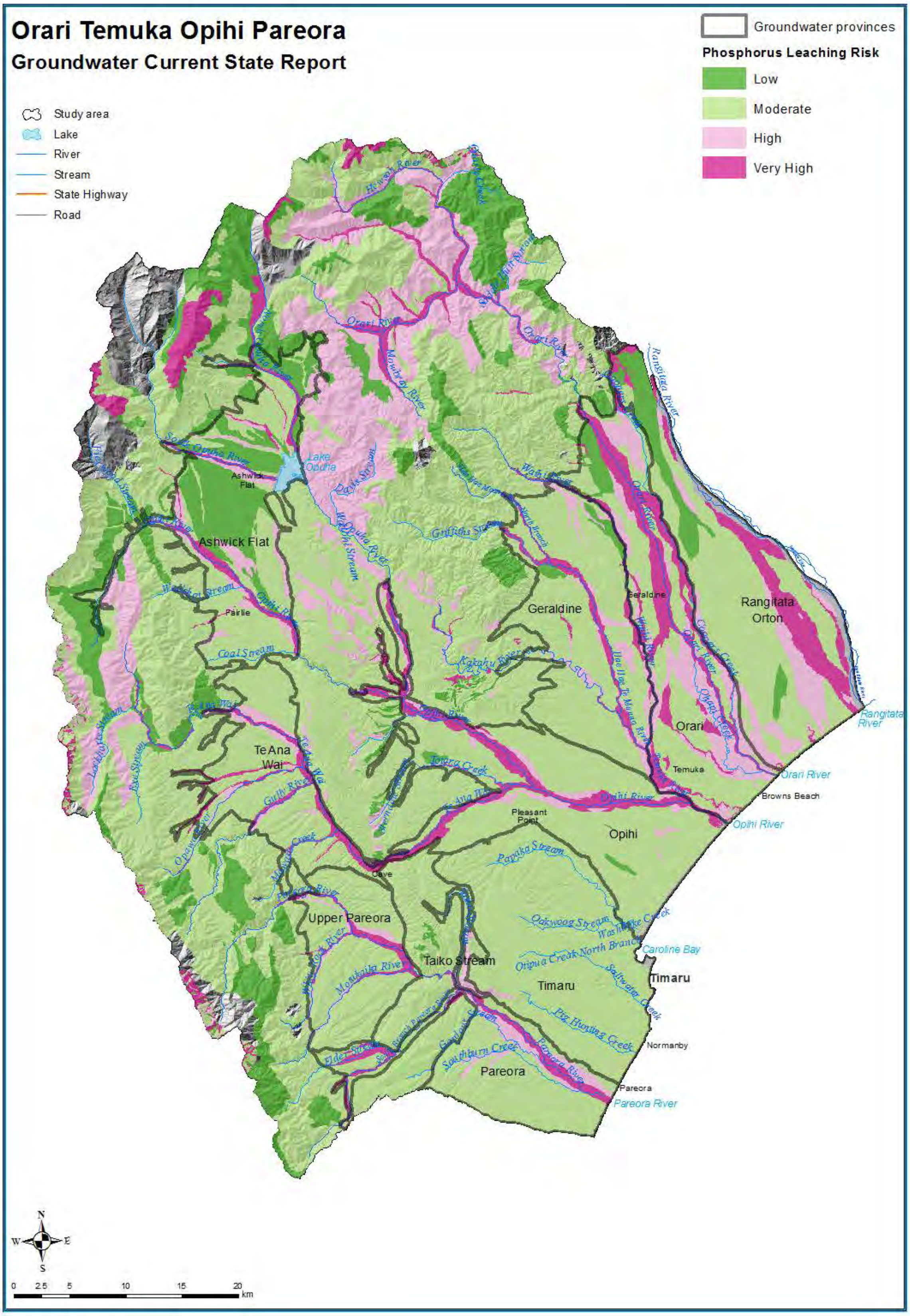

Figure 4-5: Phosphorus leaching risk as determined by Webb, *et al.* (2010)

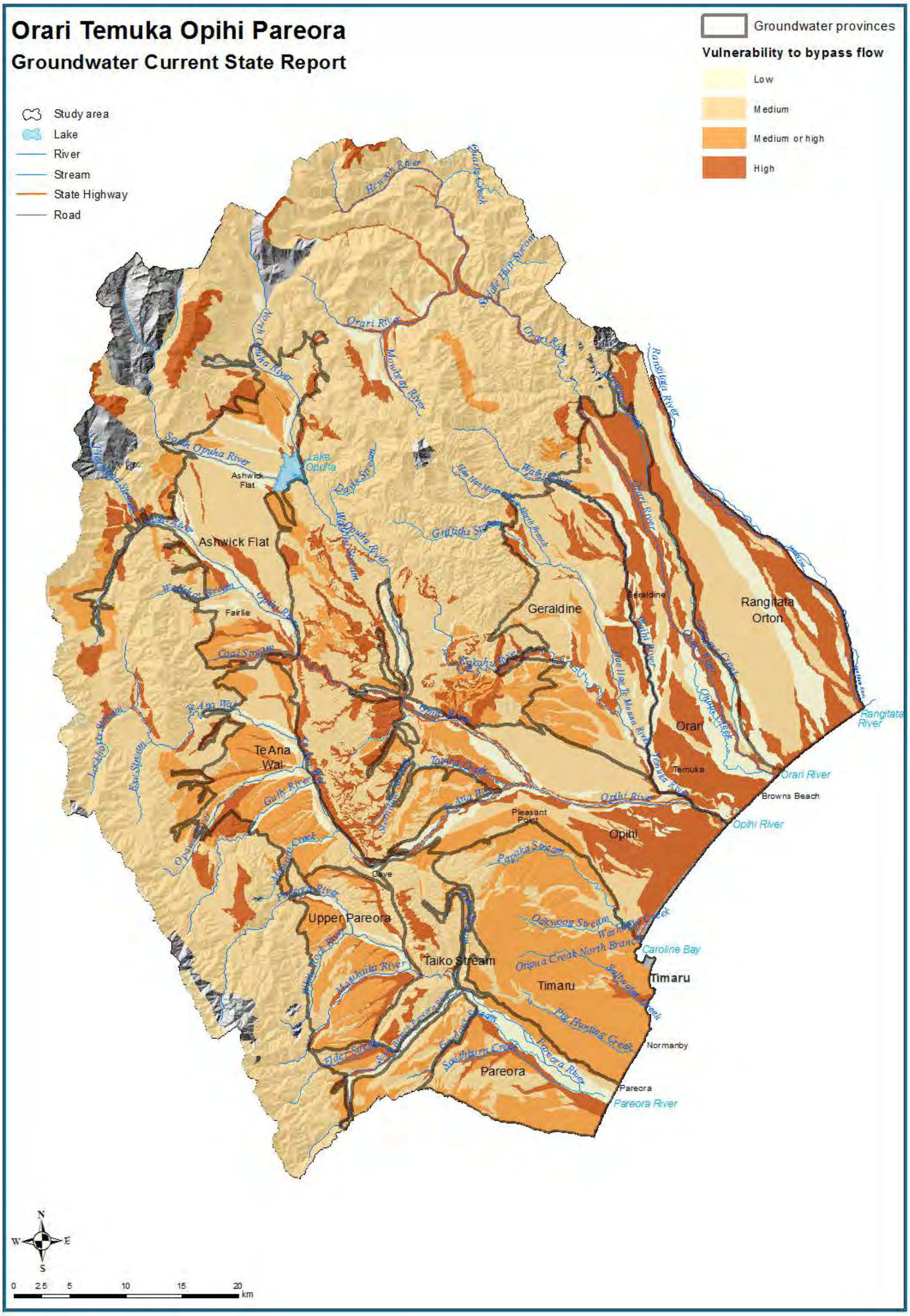

Figure 4-6: Bypass flow risk as determined by Webb, *et al.* (2010)

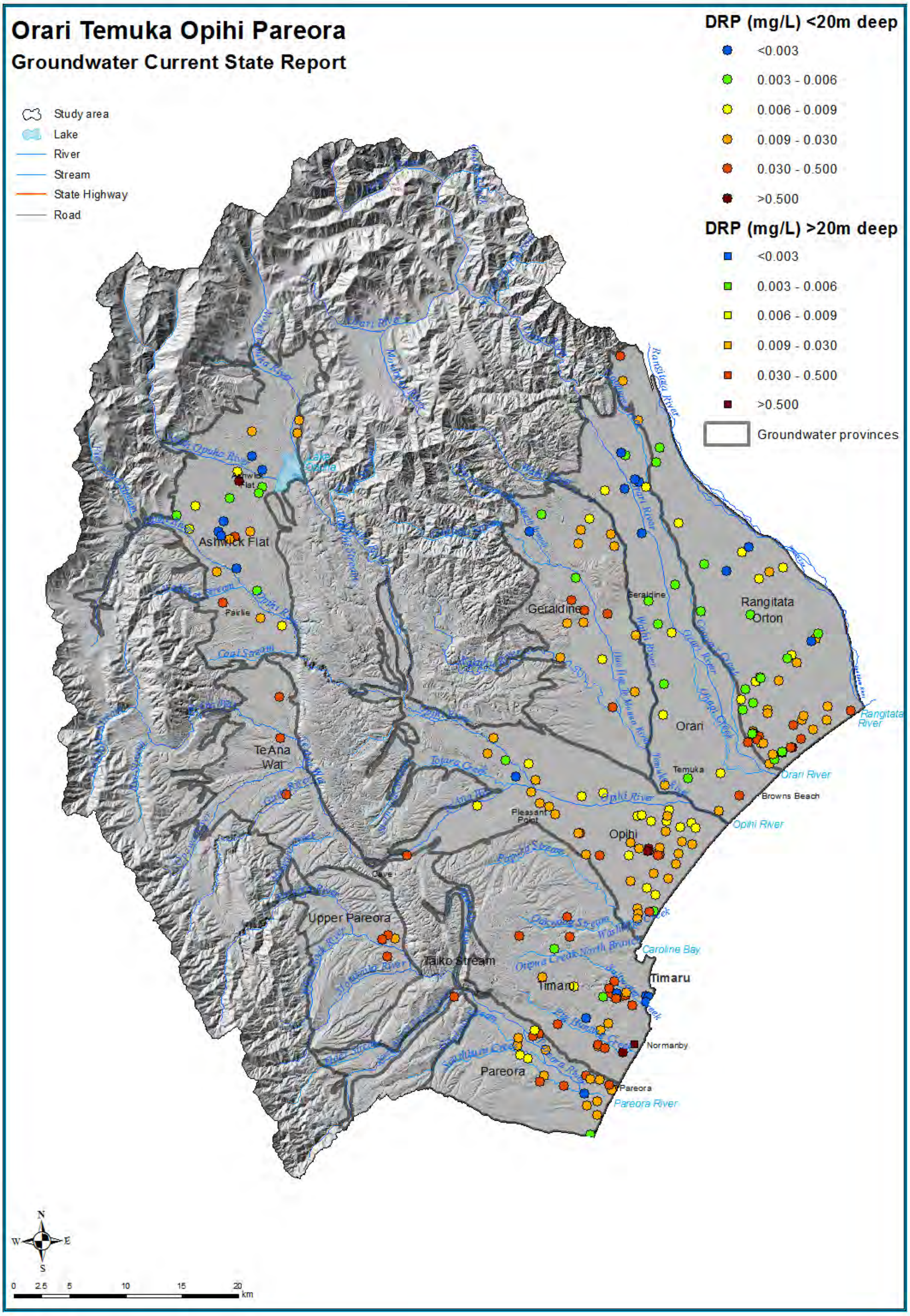

Figure 4-7: Highest DRP concentrations ever recorded in each well in the OTOP study area

These guidelines are primarily applicable to “wade-able” gravel or cobble bottomed rivers and streams. Application of DRP concentrations for a specific river also requires consideration of its flow regime. Guidelines do not address macrophyte abundance, which typically dominate in heavily silted, spring-fed, plains streams (Stevenson, *et al.,* 2010). For Canterbury streams and rivers, Stevenson, *et al.* (2010) classed concentrations above 0.003 mg/L as ‘moderately enriched’, above 0.009 mg/L as ‘enriched’ and above 0.030 mg/L as ‘excessive’. Based on this, we divide the data into the categories shown in Figure 4-7. We also include another high class (> 0.50 mg/L). This is not based on any environmental threshold, but highlights the wells with the highest recorded DRP.

We assign all non-detects a value of half of the laboratory detection limit. However, detection limits have changed over time, as have analysis methods. It varies from 0.001 to 0.1 mg/L. Non-detects with a higher limit may indicate concentrations that are higher than actually present. However, we keep these values (rather than delete them) as they help with the overall interpretation and there are other readings that agree with these concentrations.

Coastal Plains
Elevated DRP concentrations in shallow groundwater are potentially attributable to land use or geological influences. In deeper wells, elevated concentrations can be due to anoxic conditions, aged groundwater, and dissolution of aquifer material. By province:

- **Rangitata-Orton:** Has one shallow well (K38/0371) whose groundwater has a maximum DRP concentration above 0.5 mg/L (0.63 mg/L). This groundwater also has nitrate-N concentrations regularly above the drinking water MAV, and several *E. coli* detections. The high DRP concentrations are therefore likely to be due to land use activities. Other nearby groundwater has excessive or enriched DRP concentrations, likely associated with wastewater irrigation. There is a cluster of wells of different depths near the Rangitata Huts. Groundwater from these wells have decreasing DRP concentrations with depth, indicating that the elevated DRP concentrations are likely to be from the land use rather than natural sources. There is one shallow well at the western inland area of the province whose groundwater has high DRP concentrations. Groundwater from this well also has nitrate-N concentrations above background levels and receives LSR. Therefore, it is likely that the DRP may be elevated due to land use activities.

- **Orari**: Has one deep well whose groundwater has high DRP concentrations. This is likely to be natural and may represent older groundwater. Due to significant recharge of groundwater from the Orari River, DRP concentrations in this province may remain low in shallow groundwater, even though there are large areas that are prone to bypass flow.

- **Geraldine**: Has two deep and two shallow wells whose groundwater has elevated DRP concentrations. DRP in groundwater from the deepest well is likely to be natural. The other deep well (30 m deep) is near the Geraldine basalt outcrop. This may introduce phosphorus into the local groundwater. One shallow well whose groundwater has high DRP also has elevated nitrate-N concentrations. This may indicate the groundwater is affected by land use activities, or natural sources (e.g. Geraldine basalt).

- **Opihi**: Has two wells whose groundwater has DRP concentrations above 0.5 mg/L. These wells are near the Seadown fertilizer storage facility, the likely contamination source. There appears to be a plume of DRP (similar to nitrate-N), which extends from this site towards the coast (in the direction of groundwater flow) with groundwater from wells downgradient from the site having excessive DRP. Groundwater contamination downgradient from this site has previously been studied and reported by Smith (1993b). High DRP concentrations in a 24 m deep well indicates either that DRP is travelling deeper into the aquifer or a natural source of phosphorus. Shallow groundwater is enriched in DRP, with slightly lower concentrations near the area recharged by the Opihi River. Deeper groundwater is enriched or high in DRP. This may be due to a mix of natural sources and land use activities. Some groundwater also has elevated nitrate-N concentrations and/or *E. coli* detections indicating that land use could also be the source.

Inland Basins
Elevated DRP concentrations in shallow groundwater are generally from land use, especially when encountered with elevated nitrate-N and *E. coli* detections. Elevated concentrations in deep

groundwater are typically due to aquifer conditions but there are instances attributable to land use effects. By province:

- **Ashwick Flat:** One shallow well has had groundwater with DRP concentrations above 0.5 mg/L. The two samples available (from 2000 and 2015) are very different in terms of nitrate-N, DRP and DO concentrations. This may be due to altered recharge conditions, a change in land use, or a sample mix up. Re-sampling may be necessary. Of the two deep groundwater samples with high DRP concentrations, one is likely to be natural, but the other (30 m deep) has increasing nitrate-N concentrations and numerous *E. coli* detections, indicating that there may be land use impacts on the deeper groundwater.

- **Te Ana Wai:** Groundwater from three wells (two deep and one shallow) has been tested for DRP. All have high concentrations. DRP in deep groundwater is likely from natural sources of phosphate. Shallow groundwater also has slightly elevated nitrate-N concentrations and is in an area with potential high bypass flow, so the DRP could be from natural or anthropogenic sources.

- **Upper Pareora:** Three wells all have groundwater with high DRP. This groundwater is very old so the phosphorus is likely to be natural. Groundwater from the shallow well has much lower DRP concentrations than in the deep wells but is still enriched. This shallow groundwater has been dated at about 1 year, with high nitrate-N concentrations, and the well is in an area of high phosphorus leaching risk. This indicates that the DRP is likely enriched due to local land use.

Downlands
High DRP concentrations in shallow groundwater is generally due to land use. Deep groundwater in this environment is more DRP enriched than the others. This is attributable to the local geology. By province:

- **Taiko Stream:** No wells have been sampled in this province.

- **South Branch Pareora:** One deep well has groundwater tested for DRP. Concentration was elevated, but not as high as deep groundwater of the Upper Pareora province. Based on the very old age of the groundwater, the DRP is likely from natural sources.

- **Timaru:** Has two wells with groundwater DRP concentrations above 0.5 mg/L. Groundwater from both wells also had *E. coli* detections; the deeper well may be affected by a septic tank. Groundwater from many wells has excessive DRP. This may be due to interaction with the Timaru basalt or long residence times. Groundwater with lower DRP concentrations could indicate different recharge sources or travel pathways.

- **Pareora:** Has many deep wells with groundwater with enriched or excessive DRP concentrations, likely from natural sources. Groundwater from shallow wells is also enriched or excessive. This may be due to natural or anthropogenic sources. Groundwater from some shallow wells located in areas with high phosphorus leaching risk or areas prone to bypass flow that has *E. coli* detections, indicating that land use could be the source of some of the phosphorus enrichment in shallow groundwater.

4.5.5 DRP trends in groundwater

For most monitoring wells, there is insufficient record of DRP for trend analysis. DRP has not always been a part of the regular monitoring; only analysed during various investigations.

Following the Webb, *et al.* (2007) publication of potential for phosphorus leaching, Environment Canterbury analysed DRP in its 2007 annual groundwater quality survey to characterise the concentrations in Canterbury groundwater. DRP was also included in the 2008 annual survey but it took until 2014 for it to become a regular parameter in the monitoring programme after further interest in its potential to leach to groundwater.

There are only two wells in our study area whose groundwater is regularly tested for DRP. One well (J39/0109) is part of the National Groundwater Monitoring Programme and the other (K38/0172) is part

of a targeted programme to monitor the Seadown fertiliser storage facility. Figure 4-8 shows the trends for these wells. We exclude one point from 1994 from Figure 4-8 for clarity.

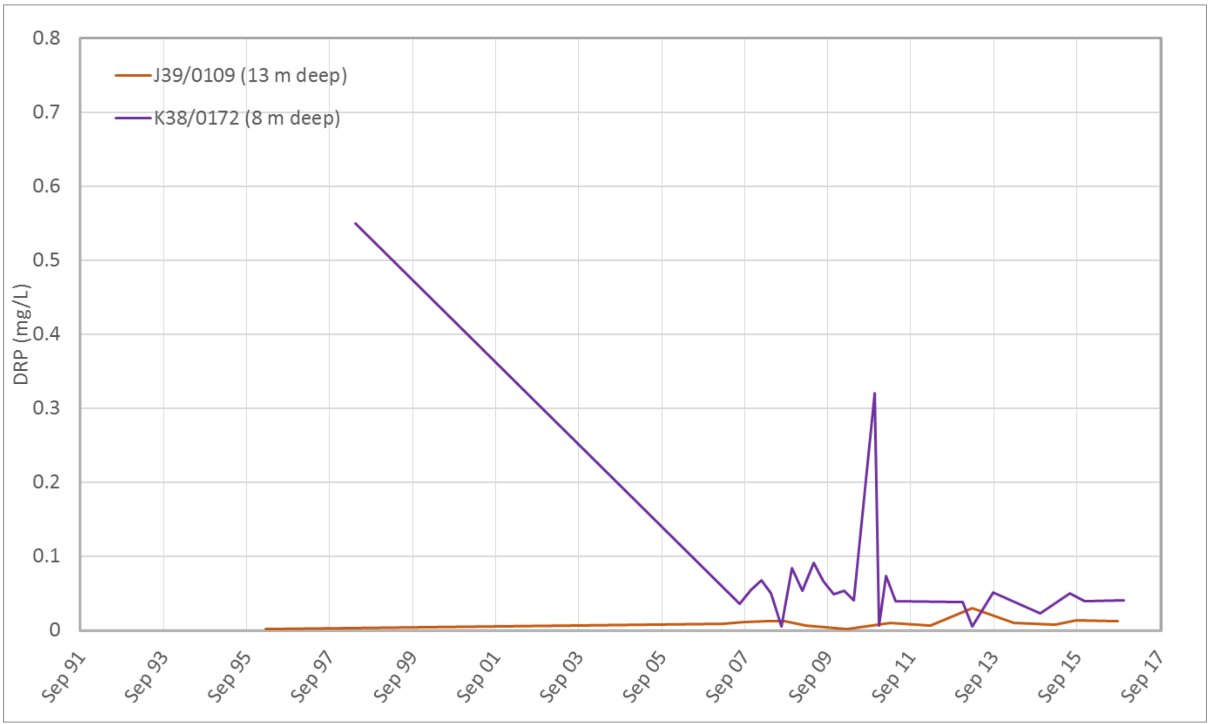

Figure 4-8: Long-term DRP trends for wells J39/0109 and K38/0172

Groundwater from J39/0109 was not tested for DRP between 1996 and 2007, and K38/0172 between 1998 and 2007, but “orthophosphate” was measured during this time, which was usually below the detection limit. It appears that the orthophosphate was higher in 1999 and decreased to lower concentrations, which seems to also fit DRP data. Other results are also available for “phosphate phosphorus” between 1995 and 1999 that indicate very high concentrations at times (up to 2.5 mg/L).

There are also some long-term data available from consent condition monitoring for a few other wells. K38/0371 and K38/0747 (near Clandeboye dairy factory) have fairly long monitoring records. Figure 4-9 shows their trends. Their monitoring frequency increased to monthly in 2011 but monitoring of K38/0371 stopped in 2013. Since monthly sampling commenced, high spikes in DRP concentrations have been detected on regular basis. It is possible that there were changes in the land management practices that resulted in higher concentrations of DRP being flushed into groundwater.

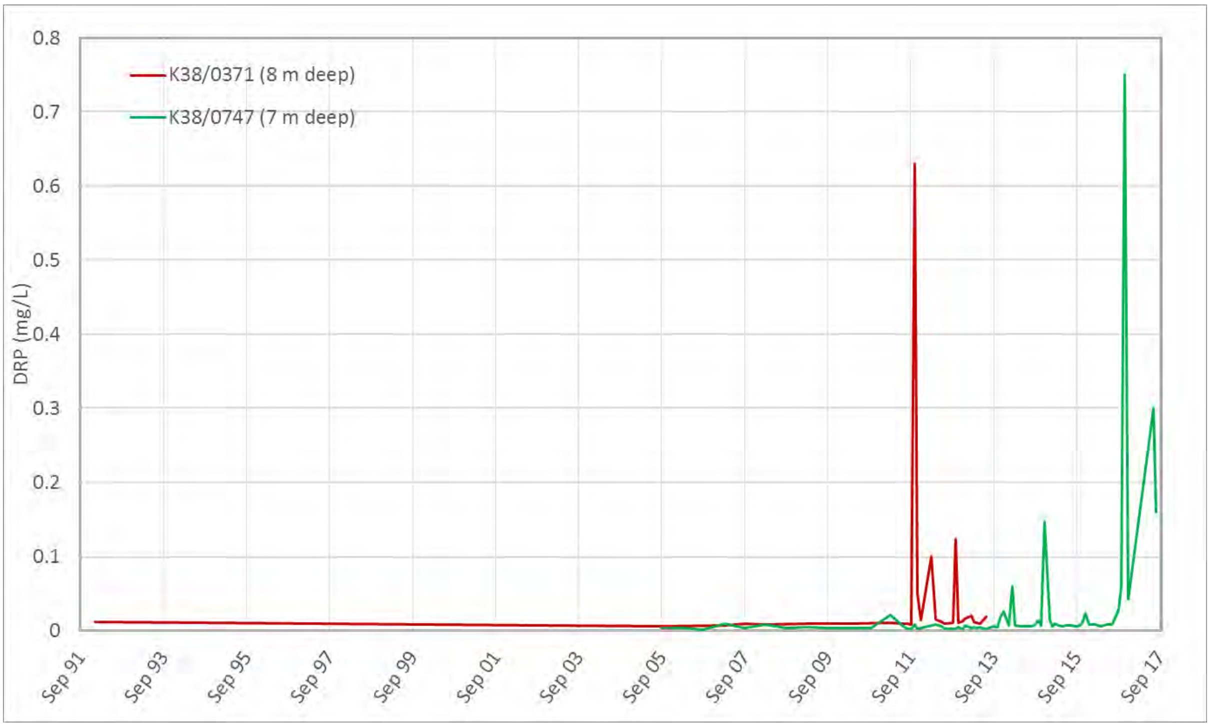

Figure 4-9: Long-term DRP trends for consent monitoring wells K38/0371 and K38/0747

4.6 Sulphate

4.6.1 Sources and transport

SO_4 occurs naturally in groundwater although SO_4-bearing minerals, such as gypsum, are largely absent in New Zealand geology. Oxidation of pyrite and/or sea spray tend to be the main natural sources of SO_4 in New Zealand groundwater. Pyrite and volcanic deposits are present in lignite/coal seams and potentially in peat (Burbery & Abraham, 2016). Concentrations can also be elevated due to fertiliser use.

Rainfall or irrigation carries SO_4 into groundwater. More intensive land use often results in higher concentrations. SO_4 travels with groundwater until it discharges in spring-fed streams, rivers, or offshore. SO_4 concentrations in groundwater only decrease if they are diluted through mixing with water of lower SO_4 concentrations or if it is reduced under anoxic conditions. SO_4 reduction requires a more reducing environment than nitrate-N, so SO_4 can persist in denitrifying areas. SO_4 from the surface takes time to move down into the deeper parts of the aquifer and concentrations are generally highest near the water table.

4.6.2 Why we care about concentrations in groundwater

A report on the state of groundwater quality in New Zealand (Ministry for the Environment, 2007) identified SO_4 concentrations in excess of background levels as one of the indicators of human influence. The drinking water GV for SO_4 is 250 mg/L because of the taste threshold. Because it does not pose a risk to health, it has not received as much attention as nitrate-N. SO_4 is often applied above plant requirements because it is not considered to be an environmental pollutant.

4.6.3 Concentrations in groundwater

Figure 4-10 shows the highest SO_4 concentrations recorded in each well in our study area. Groundwater from three wells exceeds the GV and one was at the GV. These wells are shallow and impacted by fertiliser storage or landfill. Groundwater with higher concentrations of SO_4 occurs in areas of intensive land use, which also has higher nitrate-N concentrations. Natural SO_4 concentrations in groundwater

are likely to be less than 7.5 mg/L, but concentrations in deeper groundwater, and groundwater from wells screened under loess may be higher.

Coastal Plains
Groundwater tends to have low concentration of SO_4. Exceptions are in low DO conditions, where impacted by land use, or by geology. By province:

- **Rangitata-Orton:** Groundwater from most of the deeper wells has low SO_4 concentrations indicating that background concentrations are low; probably less than 7.5 mg/L. Where groundwater has slightly higher SO_4 concentrations, it also has elevated nitrate-N concentrations and therefore likely from anthropogenic sources. Shallow groundwater shows higher SO_4 concentrations than deeper groundwater, and this is likely due to land use effects. The highest SO_4 concentrations are near Clandeboye (corresponding with high nitrate-N); land that receives discharges from the dairy factory. Closer to the Rangitata River concentrations are lower due to river recharge.

- **Orari:** Groundwater from deep wells has SO_4 concentrations below 7.5 mg/L. This groundwater also has low- or mid-range DO, and in some areas conditions could be suitable for reduction of SO_4. In shallow groundwater, SO_4 concentrations are mostly low but from a few wells might be elevated due to land use effects. Groundwater from one well had maximum SO_4 concentration of 68 mg/L. This is likely due to the influence of peat deposits within which this well is screened.

- **Geraldine:** Groundwater from most wells has SO_4 concentrations below 15 mg/L. Groundwater from many wells has low- or mid-range average DO and in some areas, conditions at times could be suitable for the reduction of SO_4. Groundwater in some shallow wells with elevated SO_4 concentrations may be due to land use effects.

- **Opihi:** Deep groundwater generally has low SO_4 concentrations, but near the Kowai Formation SO_4 concentrations are slightly higher. Shallow groundwater near the Opihi River generally has low SO_4 concentrations due to river recharge. In areas dominated by LSR, SO_4 concentrations are higher due to land use impacts. Groundwater downgradient from the Seadown fertiliser storage has very high SO_4 concentrations, with groundwater from one well exceeding the GV. Another well with groundwater high in SO_4 is downgradient from a wastewater treatment plant and could also be affected by seawater.

Inland Basins
Groundwater across this environment is generally low in SO_4. By province:

- **Ashwick Flat:** Deep groundwater generally has low SO_4 concentrations. Shallow groundwater has variable concentrations. Groundwater with higher SO_4 concentrations also has higher nitrate-N concentrations, indicating land use impacts.

- **Te Ana Wai:** Groundwater has low SO_4 concentrations.

- **Upper Pareora:** Groundwater from four wells has been sampled. Most deep groundwater has low SO_4 concentrations, while the outlier has slightly higher natural SO_4 concentration. The shallow well is near an irrigated dairy farm and located on light soils. The slightly higher SO_4 concentration in groundwater from this well may be due to land use impacts.

Downlands
Low SO_4 persist across much of the environment. The exception is the Timaru province where high ionic content and land uses may be the cause of elevated concentrations. By province:

- **Taiko Stream:** No wells sampled.

- **South Branch Pareora:** Groundwater from a deep well is very old with low SO_4 concentrations.

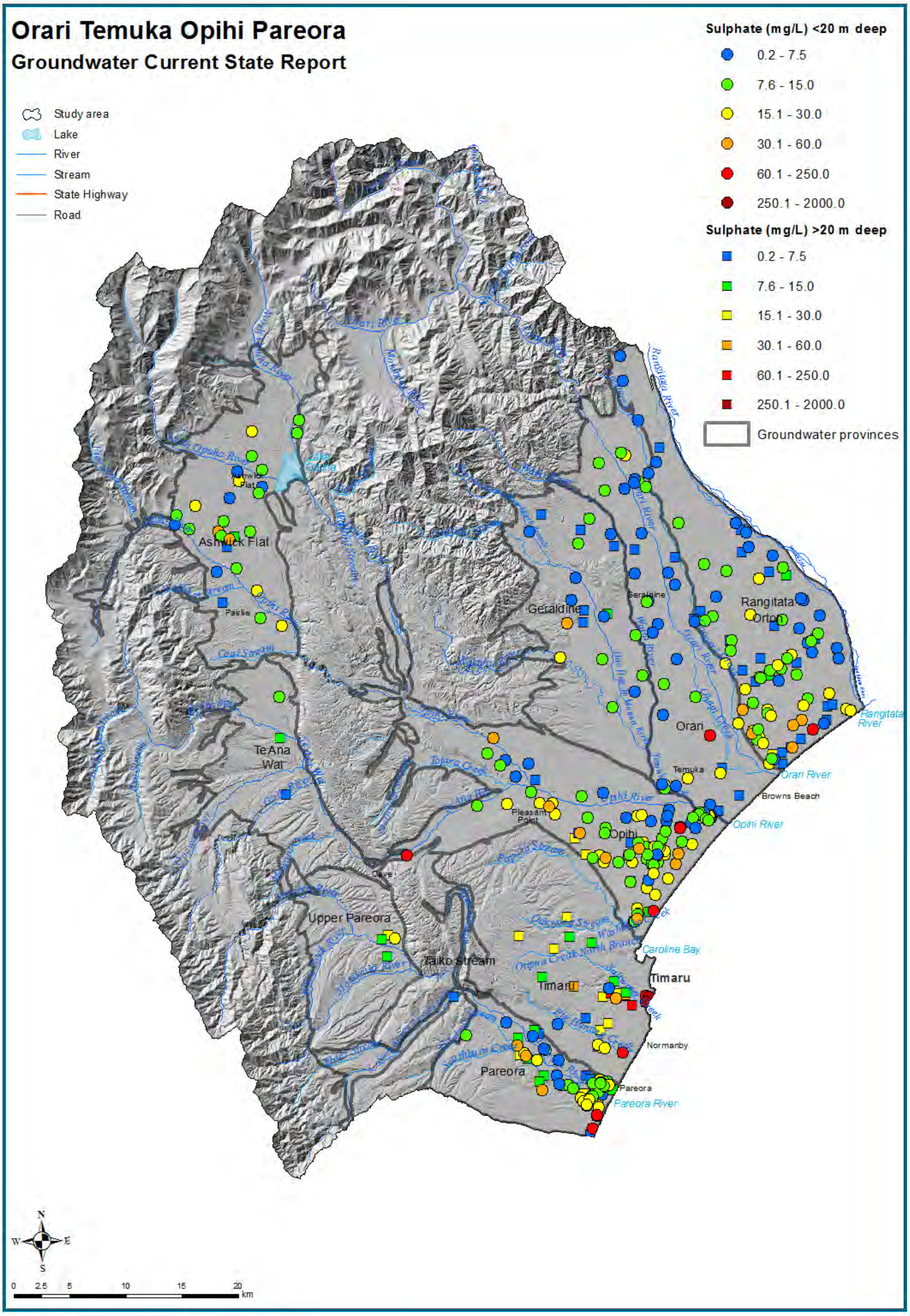

Figure 4-10: Highest sulphate concentrations ever recorded in each well

- **Timaru:** Deeper groundwater generally has higher SO_4 concentrations than other parts of the study area. Groundwater has higher concentrations of most ions, possibly due to some evaporation of recharge water on the loess. This may be the reason for the higher SO_4 concentrations. Deep groundwater with SO_4 concentrations below 7.5 mg/L corresponds to very low DO concentrations making it possible that SO_4 reduction has occurred. Shallow groundwater with SO_4 concentration above GV is from two shallow wells located near a landfill. Groundwater from other shallow wells has variable SO_4 concentrations. This may be due to a mix of natural and land use effects.

- **Pareora:** Deep groundwater has low SO_4 concentrations. Where deep groundwater has Stiff diagrams similar to wells screened under loess it has slightly higher concentrations. Deep groundwater with high SO_4 and slightly elevated nitrate-N concentrations, indicates rapid recharge of the deep groundwater. SO_4 concentrations in shallow groundwater are variable but in general the concentrations are higher to the south of the Pareora River. The south side is dominated by LSR and therefore shows greater land use impacts compared with the area to the north.

4.6.4 Sulphate trends in groundwater

Environment Canterbury samples groundwater on a regular basis in a number of wells, to monitor trends over time. As in Section 1.7, there are 46 wells that are part of the long-term monitoring programmes. We do not present all SO_4 trends as they often follow the nitrate-N trends, but SO_4 usually has higher concentrations. Instead, we present a selection of SO_4 vs nitrate-N trends in individual wells.

Figure 4-11 demonstrates an example where the SO_4 and nitrate-N trends are quite similar. This well (K38/0148) is 9 m deep in the inland part of the Rangitata-Orton province. The spikes in concentration most likely correspond to recharge events.

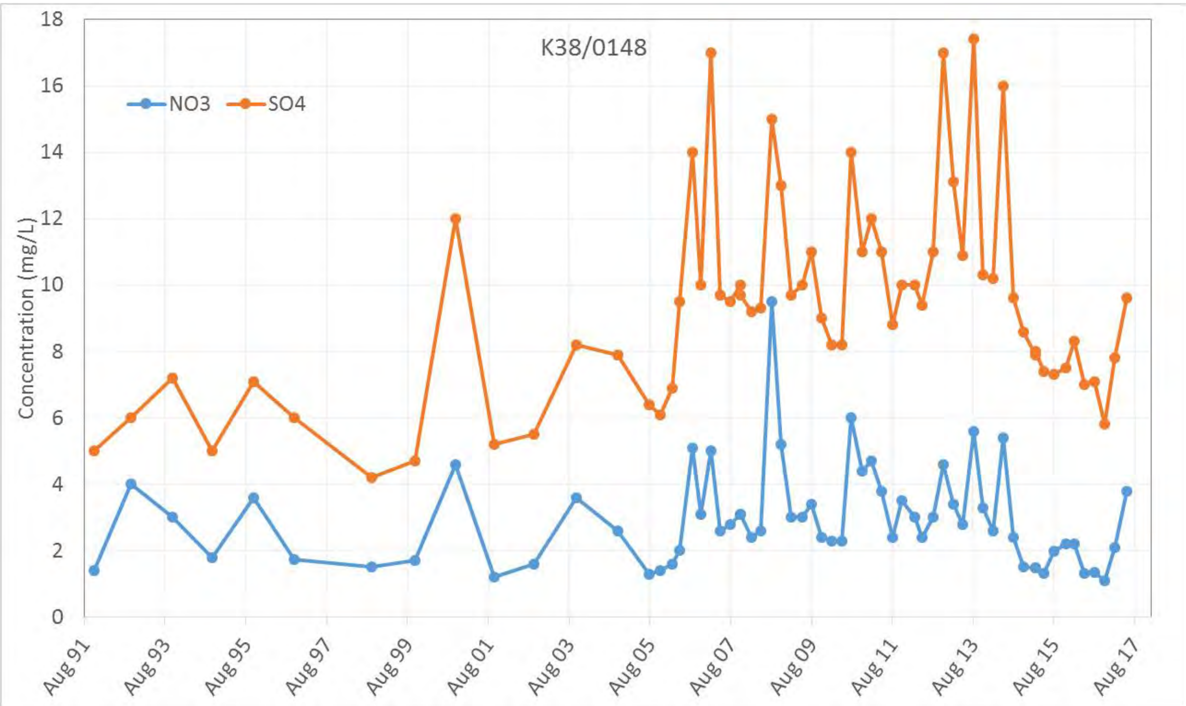

Figure 4-11: K38/0148 (Rangitata-Orton province) where sulphate and nitrate-N concentrations have a similar trend

Figure 4-12 shows why examining both SO_4 and nitrate-N trends can be useful. Around 2013 there was a decrease in nitrate-N concentrations in K38/0144 after the RSIS was commissioned. There was also a drop in SO_4 concentrations, confirming dilution effects rather than another process such as denitrification. The lower magnitude of the drop of SO_4 compared with the nitrate-N is likely due to higher concentrations of SO_4 in RSIS water and comparatively low nitrate-N.

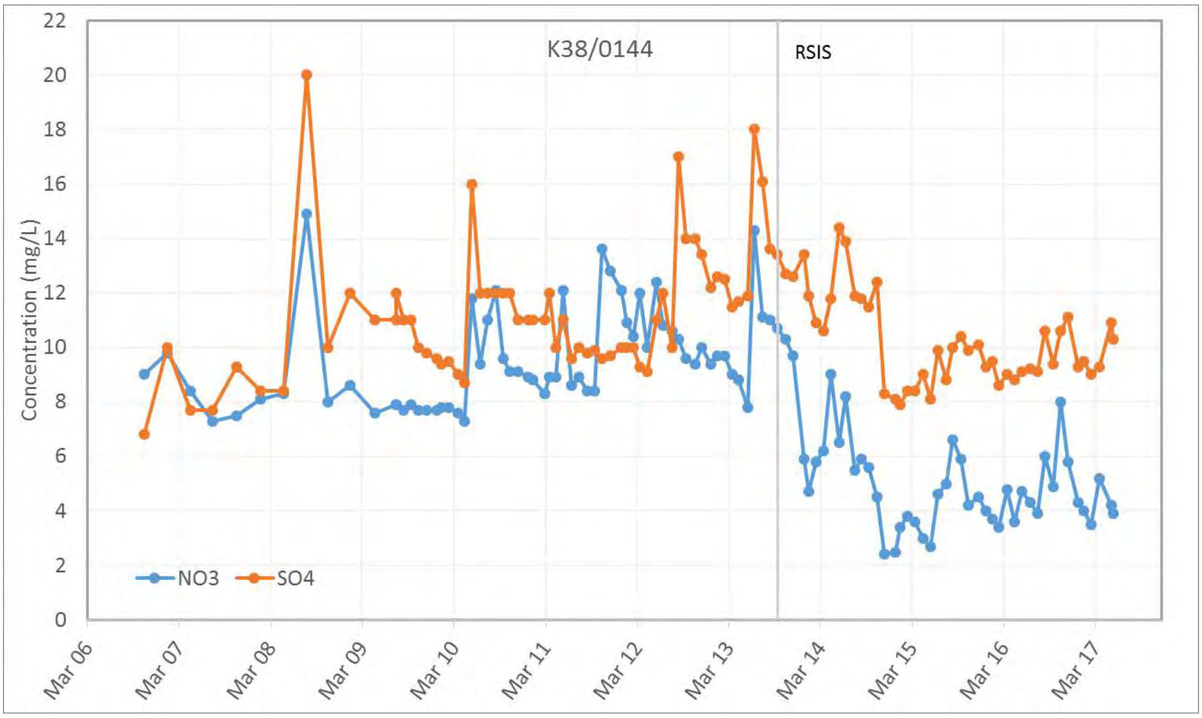

Figure 4-12: K38/0144 (Rangitata-Orton province) where dilution from RSIS has caused differing decreases in nitrate-N and sulphate concentrations

Figure 4-13 shows an example where nitrate-N concentrations are low but SO_4 concentrations are increasing. The likely explanation is that the conditions are suitable for denitrification but not for SO_4 reduction. The SO_4 shows that there are effects of land use intensification, which are not detectable in the nitrate-N trends.

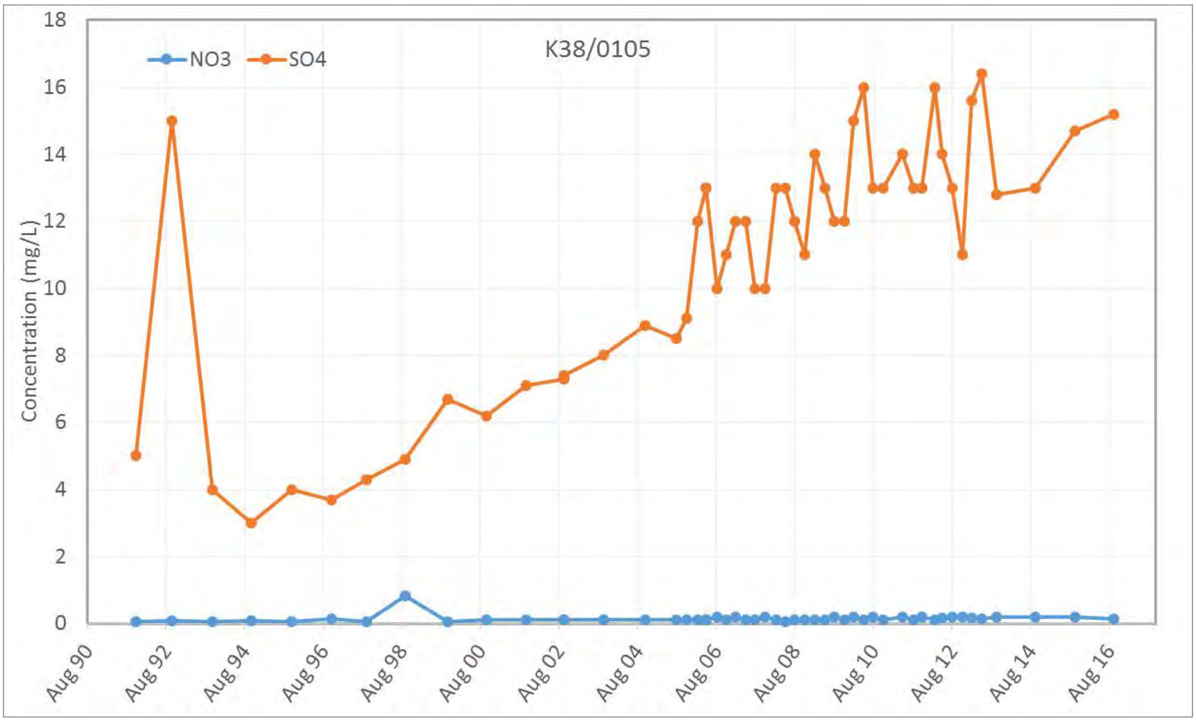

Figure 4-13: K38/0105 (near lower Orari River, Rangitata-Orton province) where sulphate concentrations are increasing but nitrate-N concentrations are low

4.7 Pathogens in groundwater

E. coli is a common gut bacterium of warm-blooded organisms and is used as an indicator for pathogens (bacteria, viruses and protozoa). It is present in high numbers in faecal material, so indicates faecal contamination. Pathogens from human or animal waste can cause contamination of groundwater and make it unsuitable for drinking. *E. coli* can enter groundwater from septic tank discharges, effluent leakage, and excreta from animals where it can infiltrate from the surface and surface water into groundwater. Because the unsaturated zone provides some pathogen removal, areas with thin soils and shallow groundwater are more prone to *E. coli* contamination, especially after rainfall or with excessive irrigation.

The MAV for *E. coli* is less than one microorganism per 100 mL of sample. Figure 4-14 indicates wells where *E. coli* has been detected in one or more groundwater samples, and wells whose groundwater has no detected *E. coli*. Detections occur throughout the study area with no clear spatial pattern. Half of all 218 wells have had detectable concentrations of *E. coli* at some stage. This is above the 40% detection rate that Hanson, *et al.* (2006) reported when they reviewed the data on a regional scale. This may be due to large areas having shallow groundwater, the influence of septic tanks, or intensive land use. *E. coli* die off over time so there is a possibility that some wells with no detection could at other times have *E. coli* present. If tested shortly after rainfall, *E. coli* could be present in some of the wells. Hanson, *et al.* (2006) note that the detection rate for Canterbury wells sampled for *E. coli* only once was lower than for wells sampled multiple times. About half (107 out of 218) of the wells in our study area have only been tested once for *E. coli*.

There is a possibility that some samples were contaminated and are not representative of the aquifer water quality. Sample contamination can occur through handling error, sample point contamination, backflow contamination or poor wellhead security. As the data set includes monitoring data from consent conditions, we are not certain of the protocol used during sample collection.

Deeper groundwater has lower rates of *E. coli* detection than shallow groundwater. 58% of shallow wells (≤ 20 m deep) and 22% of deep wells (> 20 m deep) whose groundwater has been sampled for *E. coli* have had one or more detections. From the 111 wells whose groundwater has been sampled multiple times, 61% had more than one detection. When split into two depth ranges (as above): 73% of shallow wells and 16% of deep wells with multiple samples, had more than one detection of *E. coli*.

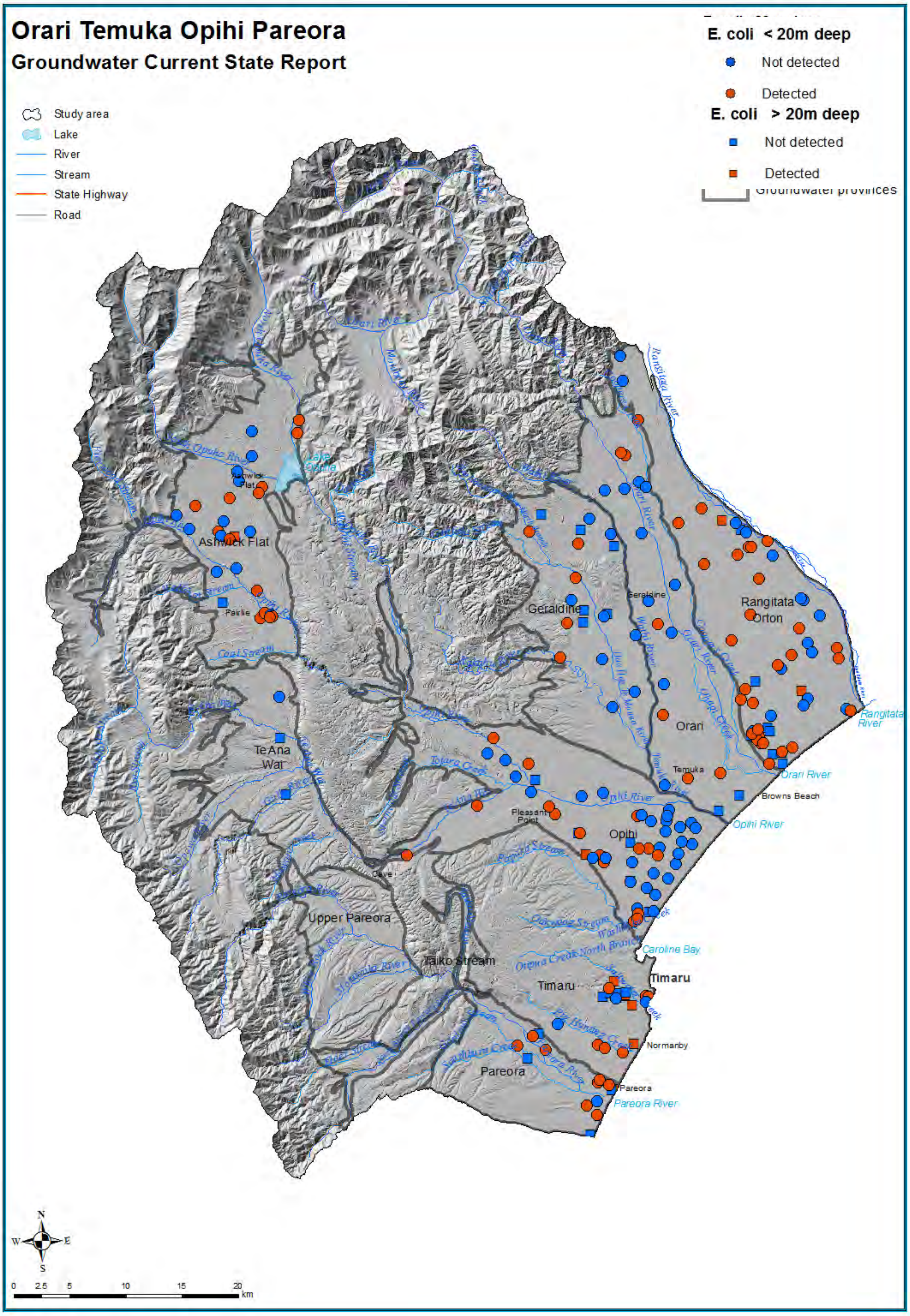

Figure 4-14: Wells where *E. coli* has been detected in one or more sample and wells with no detections

5 Conclusions

Groundwater is predominantly recharged by LSR and flow losses from major rivers. Generally speaking, recharge from river water has a lower contaminant load than LSR. Across most of the OTOP area, elevated EC indicates LSR. The exception is along the coast, where elevated EC can reflect the influence of seawater. Here $\delta^{18}O$ data is used to determine recharge source.

The impacts of LSR on groundwater is evident in groundwater across all environments. The geochemical signatures and indicators of this impact are inconsistent due to the varying type and intensity of land use, soil, distance from the coast, and differences in geology. High intensity land use is facilitated by irrigation. Changes from flood irrigation to spray have reduced groundwater recharge and thus dilution of contaminants, while also enabling increasing contaminant loads. Coastal and flat areas have soils with greater potential to leach contaminants. Instances of Na-Cl and Na-HCO_3 type groundwater across the plains reflect land use impacts, or feldspar weathering in deeper wells. In the inland basins, Na-HCO_3 type groundwater is present across all provinces suggesting aged groundwater. Ashwick Flat data suggests impacts from fertiliser, irrigation infrastructure, and land use. The fragipan of the Downlands prevents significant leaching to groundwater. Deep groundwaters from the Timaru and Pareora provinces have high chloride concentrations, reflecting the marine geology.

Nitrate-N concentrations above the MAV have been measured in many OTOP wells, including some concentrations above 20 mg/L. The coastal plains are under intensive land use and the dominant recharge source is LSR. This combination leads to higher nitrate concentrations in both shallow and deep groundwater. In the inland basins, exceedances of the nitrate-N MAV tend to be shallow groundwater near an irrigated area. High nitrate-N concentrations only occur in the Downlands where associated with a point source discharge or rapid flow path. Most wells have no nitrate-N trend. Increasing trends are seen in a handful of shallow wells across the zone, and deep wells in Rangitata-Orton and Levels Plain. Decreasing nitrate-N trends are largely attributable to dilution from RSIS infrastructure.

Nitrates persist in high DO environments. High concentrations of DO in the Coastal Plains mean nitrates persist in the shallow groundwater environment. Shallow groundwater on the Downlands has lower DO concentrations than shallow groundwater in the other environments. Areas with poorly drained soils and/or intensive land use, and deep groundwater tend to have lower DO concentrations, so are more likely to have denitrification occur, decreasing nitrate concentrations.

We attribute high concentrations of DRP in deep wells to anoxic conditions, age, and the influence of geology. In the coastal plains, elevated DRP concentrations in shallow groundwater tend to be associated with a point source discharge, or are measured along with elevated nitrate and *E. coli* concentrations suggesting impact from land use. There are no identifiable trends in DRP concentrations.

Half of all sampled wells had detection of *E. coli*. This is above the 40% rate reported by Hanson *et al.* (2006). Shallow wells have a higher detection rate than deeper wells. The same trend is seen in wells sampled multiple times.

6 Acknowledgements

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- Stephen Douglass for providing a well-rounded and thorough external review
- Carl Hanson for final review and project sign-off.

7 References

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Appendix A Stiff diagram maps for the Coastal Plains, Inland Basins, and Downlands

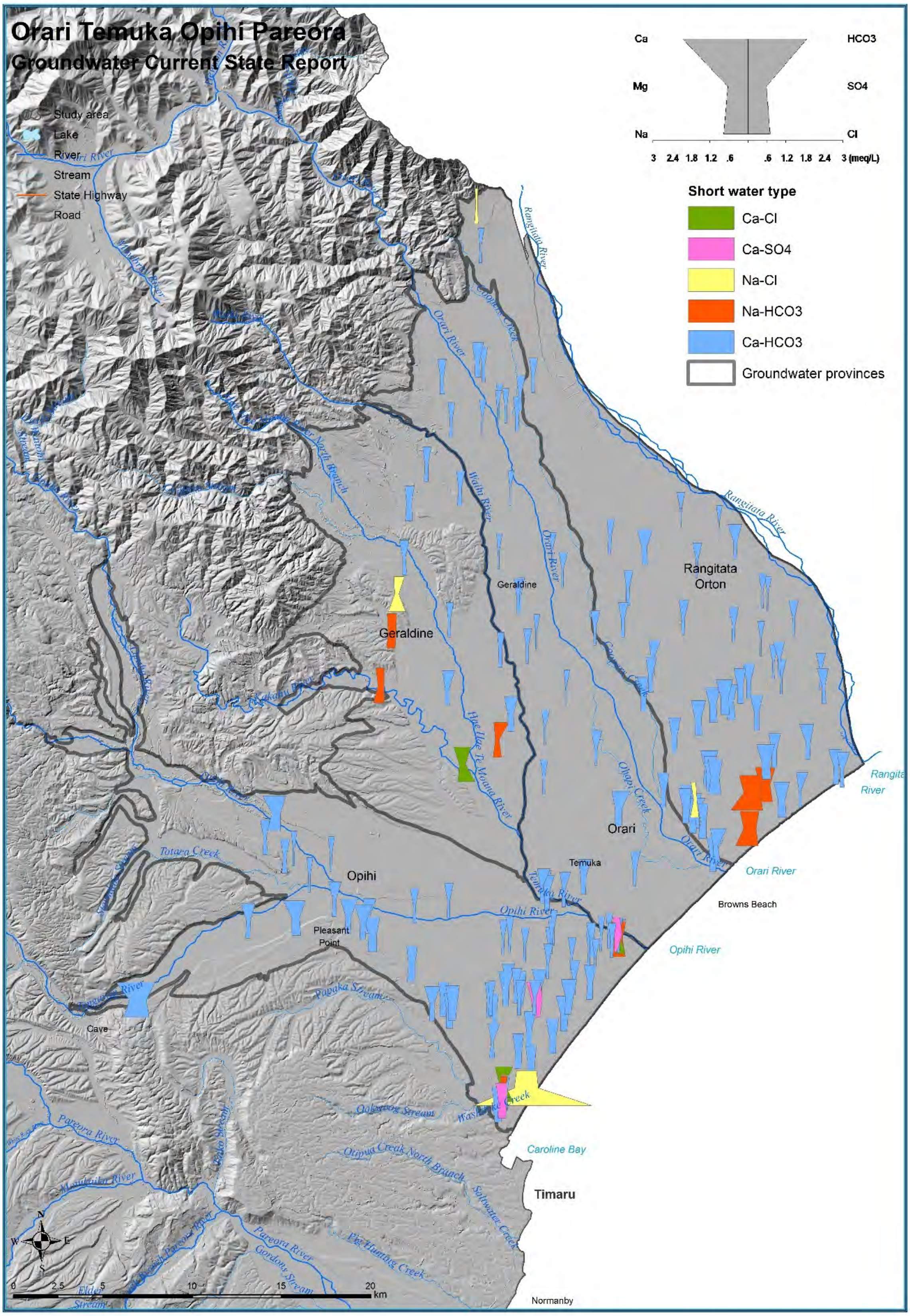

Figure A-1: Coastal Plains shallow groundwater (≤ 20 m) Stiff diagrams

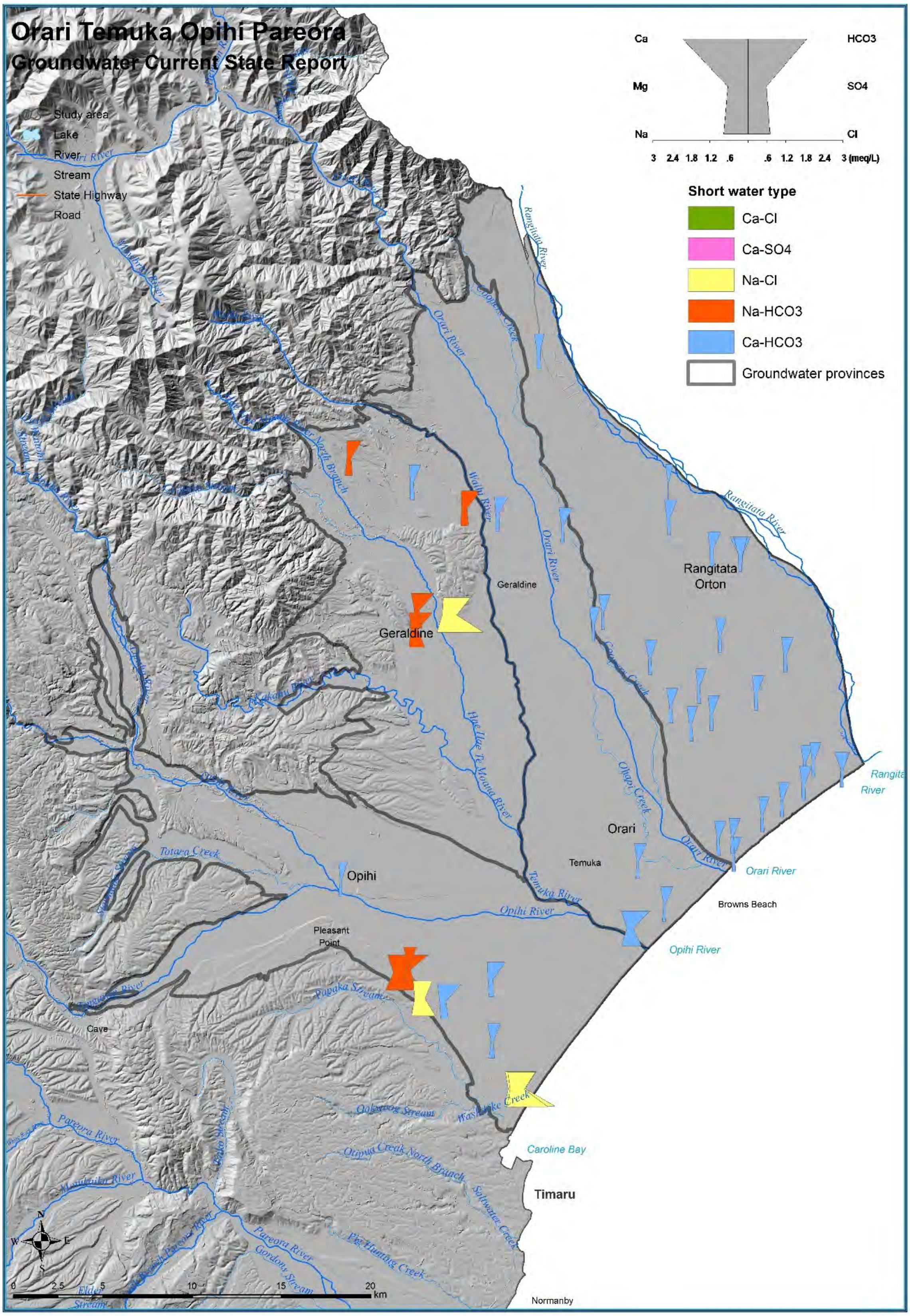

Figure A-2: Coastal Plains deep groundwater (> 20 m) Stiff diagrams

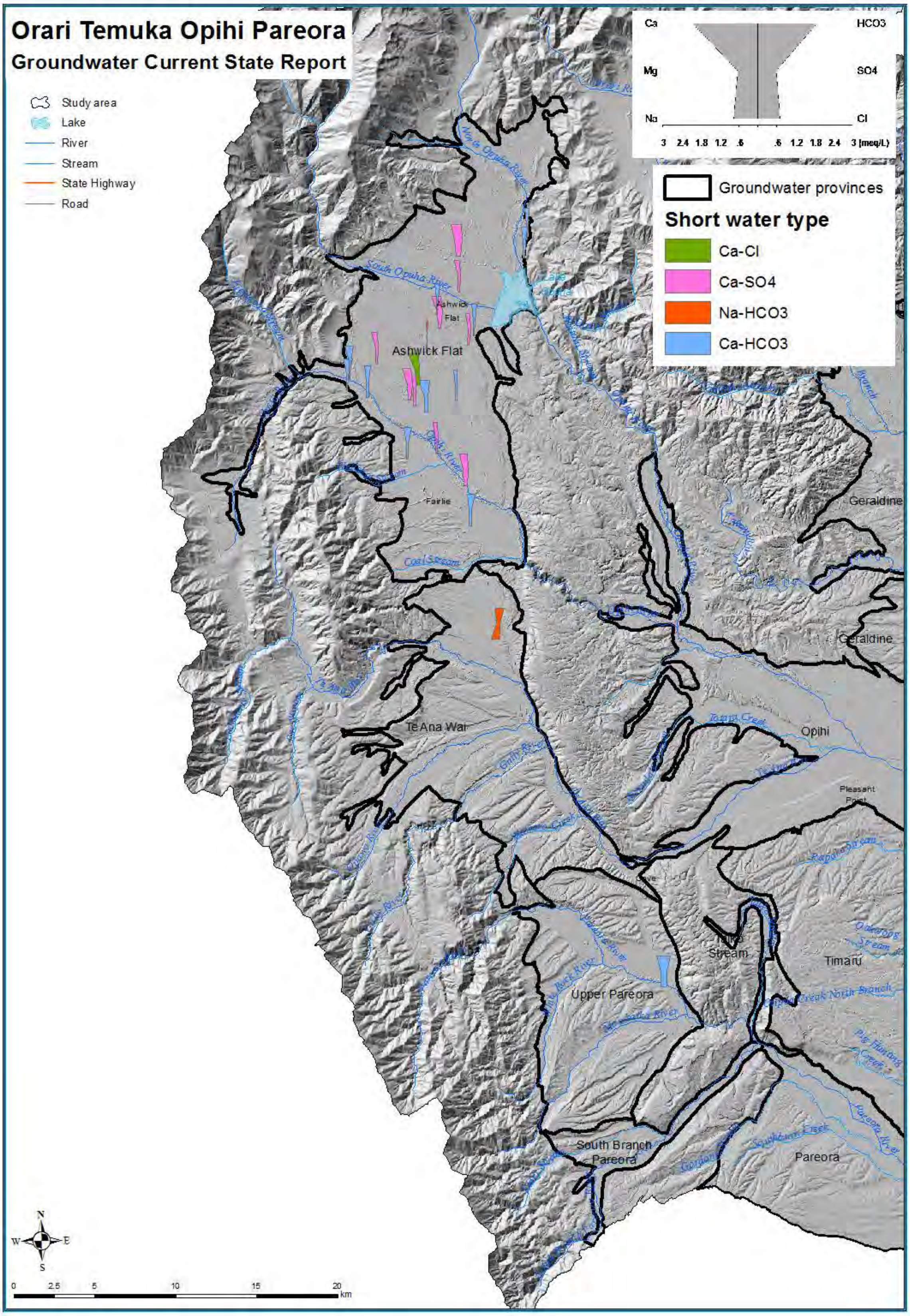

Figure A-3: Inland Basins shallow groundwater (≤ 20 m) Stiff diagrams

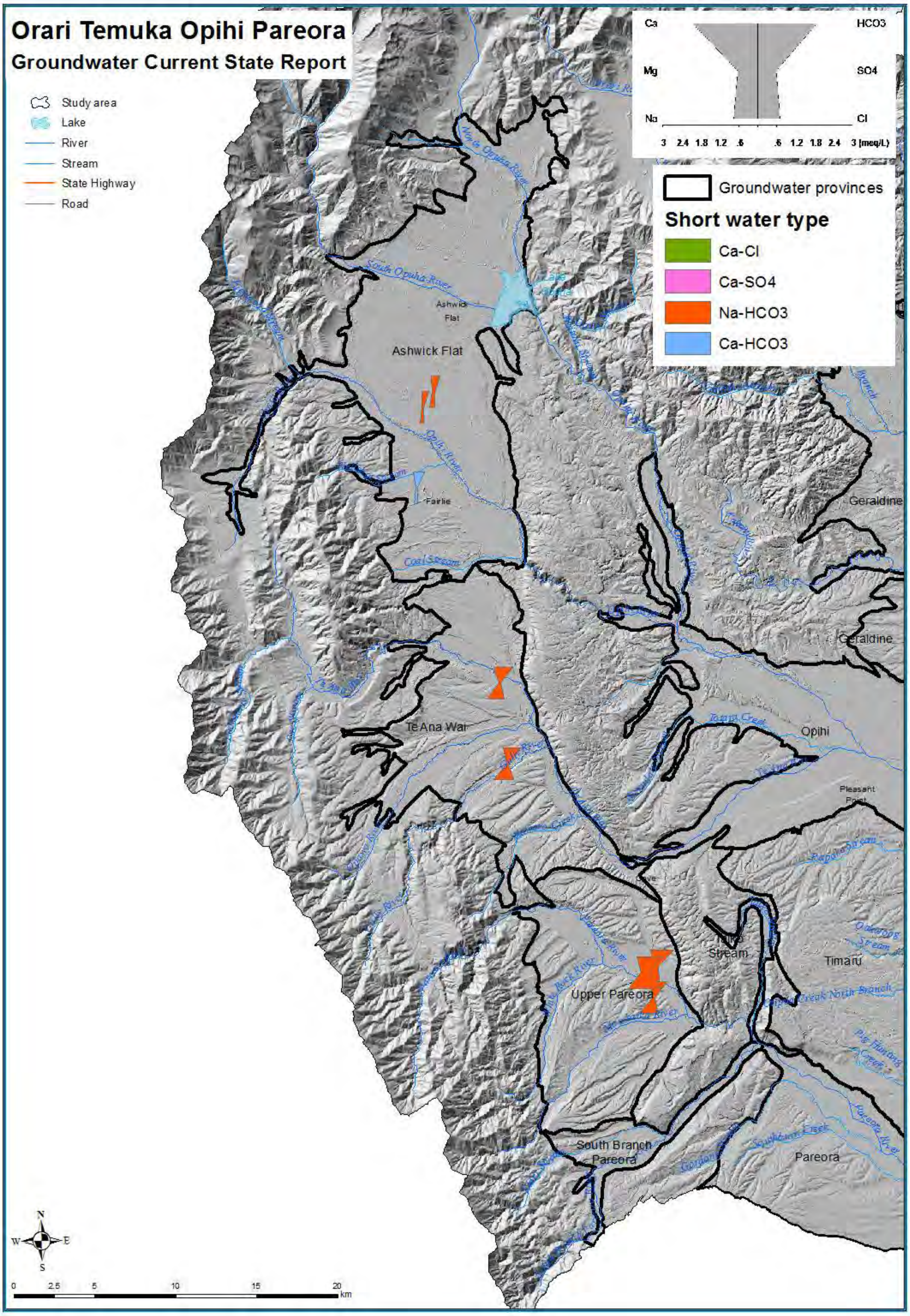

Figure A-4: Inland Basins deep groundwater (> 20 m) Stiff diagrams

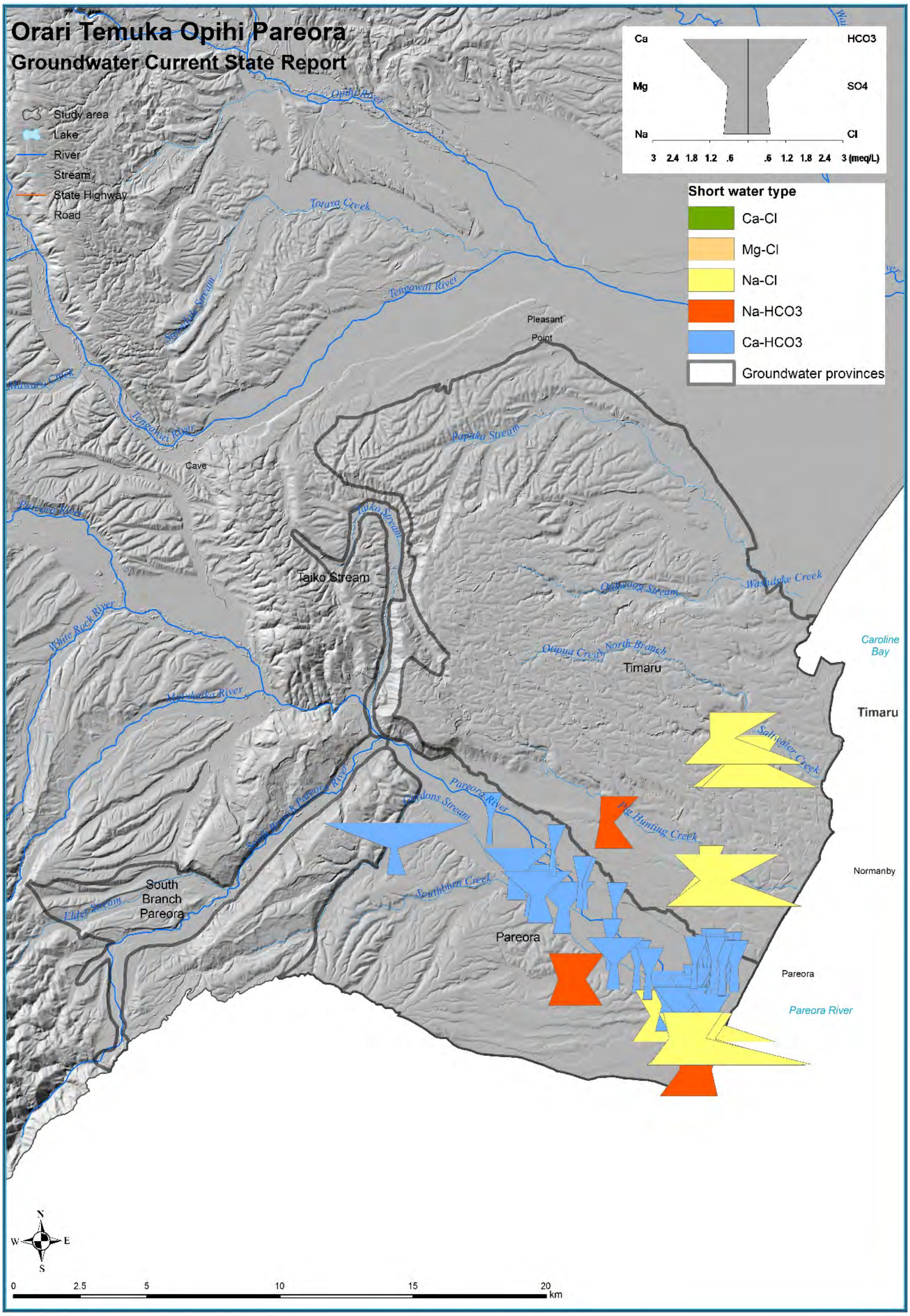

Figure A-5: Downlands shallow groundwater (≤ 20 m) Stiff diagrams

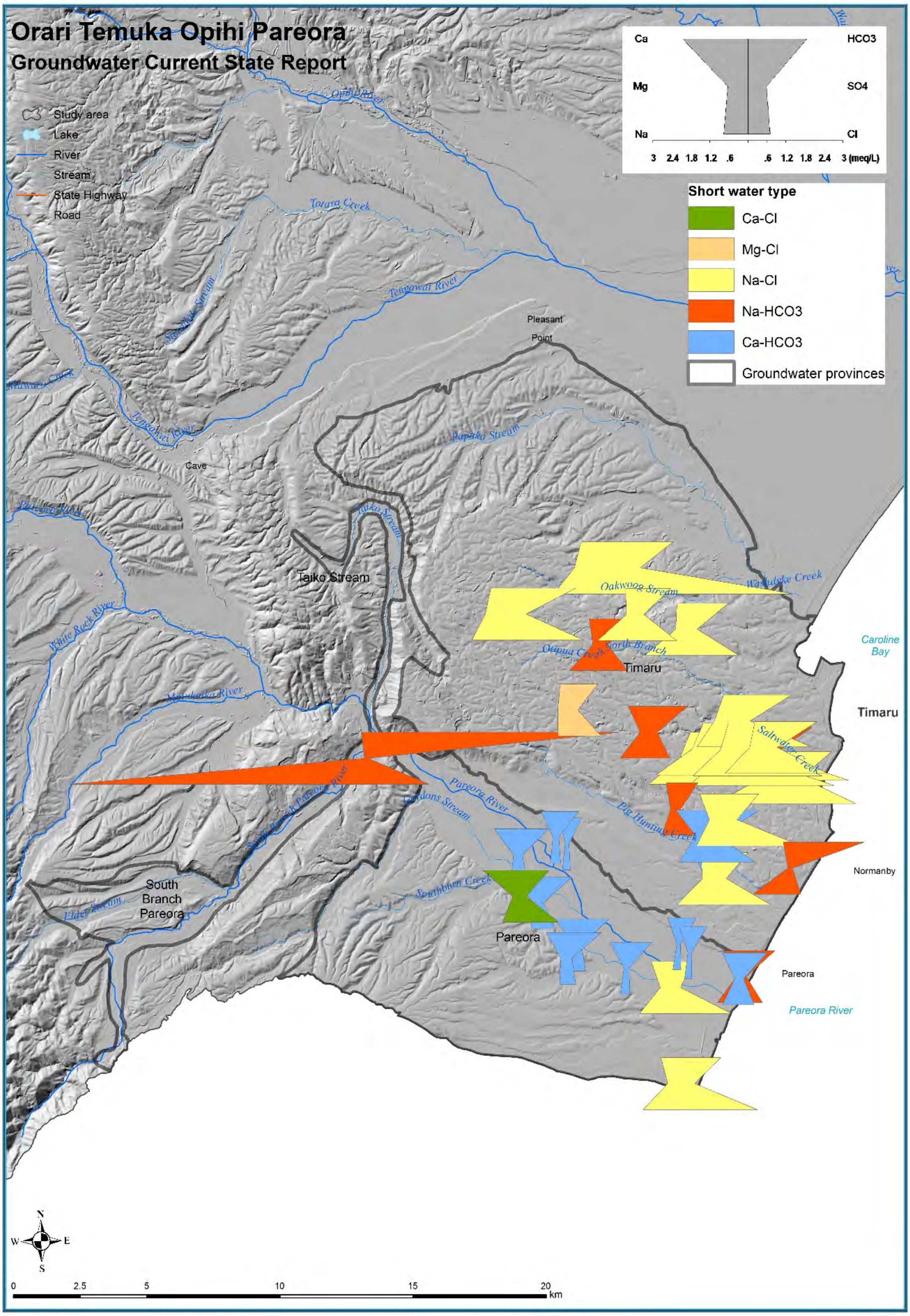

Figure A-6: Downlands deep groundwater (> 20 m) Stiff diagrams

Appendix B GVs for parameters tested in groundwater

Table B-1: GVs for parameter by guideline type

Parameter	Drinking water MAV or GV (Ministry of Health, 2008)	Stock water (ANZECC, 2000)	Irrigation water (ANZECC, 2000)
Ammonia-N (mg/L)	1.2 mg/L (GV for odour threshold in alkaline conditions)		
Arsenic (mg/L)	0.01 (MAV)	0.5	0.1 (long-term use up to 100 years) 2.0 (short-term use up to 20 years)
Calcium (mg/L)		1000	
Chloride (mg/L)	250 (GV for taste and corrosion)	-	< 175 (sensitive crops) 175–350 (moderately sensitive crops) 350–700 (moderately tolerant crops) > 700 (tolerant crops)
E. coli (MPN/100 mL)	< 1 (MAV)		
Faecal coliforms (cfu/100 mL)		< 100	< 10 (Raw human food crops in direct contact with irrigation water) < 100 (Pasture and fodder for dairy animals without withholding period) < 1000 (Pasture and fodder for dairy animals with withholding period of 5 days OR Pasture and fodder for grazing animals except pigs and dairy animals OR Raw human food crops not in direct contact with irrigation water or crops sold to consumers cooked or processed) < 10,000 (Silviculture, turf, cotton, etc. with restricted public access)
Hardness (as CaCO3, mg/L)	200 (GV for scale deposition)	< 60 (increased corrosion potential) > 350 (increased fouling potential)	< 60 (increased corrosion potential) > 350 (increased fouling potential)
Iron	0.2 (GV for staining of laundry and sanitary ware)		0.2 (long-term use up to 100 years) 10 (short term use up to 20 years)

Parameter	Drinking water MAV or GV (Ministry of Health, 2008)	Stock water (ANZECC, 2000)	Irrigation water (ANZECC, 2000)
Manganese (mg/L)	0.4 (MAV) 0.04 (GV for staining of laundry and sanitary ware) 0.1 (GV for taste threshold)		0.2 (long-term use up to 100 years) 10 (short-term use up to 20 years)
Nitrate-N (mg/L)	11.3 (MAV)	90	
pH (lab)	> 7.0 (GV for plumbosolvency) < 8.5 (GV for soapy taste and feel)	6.0 – 8.5 (to limit corrosion and fouling of pumping and stock watering systems)	6.0 – 8.5 (to limit corrosion and fouling of pumping and irrigation systems)
Sodium (mg/L)	200 (GV for taste)	-	< 115 (sensitive crops) 115-230 (moderately sensitive crops) 230-460 (moderately tolerant crops) > 460 (tolerant crops)
Sulphate (mg/L)	250 (GV for taste)	> 1,000 (adverse effects may occur) > 2000 (chronic or acute health problems)	-
Total Dissolved Solids (mg/L) / Electrical conductivity (mS/m) (TDS=5.95*EC)	1,000 / 168 (GV for taste)	3,000 / 504 (poultry) 4,000 / 672 (dairy cattle)1 5,000 / 840 (beef cattle, horses and pigs) 10,000 / 1,681 (sheep)	< 410 / < 69 (sensitive crops) 410-821 / 69-138 (moderately sensitive crops) 821-1,944 / 138-327 (moderately tolerant crops) 1,944-3,326 / 327-559 (tolerant crops) 3,326-5,270 / 559-886 (Very tolerant crops) > 5,270 / > 886 (Generally too saline) Based on average root zone salinity tolerance and used average root zone LF of 0.33

Appendix C Exceedances of GVs

Table C-1: Number of exceedances of MAV and/or GV by well by parameter

Parameter	Drinking water MAV or GV* (MoH, 2008)	Stock water (ANZECC, 2000)	Irrigation water (ANZECC, 2000)
Ammonia-N (mg/L)	J39/0232 (2/27) J39/0297 (1/1) J39/0304 (1/1) K38/0172 (33/53) K38/0747 (1/42) K38/2377 (3/4) K39/0020 (1/1) K38/0068 (1/1)	-	-
Arsenic (mg/L)	K39/0066 (1/1)	-	-
Calcium (mg/L)	-	-	-
Chloride (mg/L)	J39/0012 (1/1) J39/0079 (1/1) J39/0087 (1/1) J39/0089 (1/1) J39/0121 (19/33) J39/0186 (1/1) J39/0232 (34/86) J39/0260 (1/1) J39/0297 (1/1) J39/0298 (1/1) K38/0111 (1/12) K39/0001 (2/2) K39/0066 (1/1) K39/0067 (1/1) K39/0068 (1/1)	-	> 175 mg/L J39/0012 (1/1) J39/0079 (1/1) J39/0082 (1/1) J39/0087 (1/1) J39/0089 (1/1) J39/0121 (28/33) J39/0186 (1/1) J39/0232 (67/86) J39/0259 (15/69) J39/0260 (1/1) J39/0261 (89/94) J39/0262 (1/1) J39/0297 (1/1) J39/0298 (1/1) J39/0299 (1/1) J39/0300 (1/1) J39/0301 (1/1) J39/0304 (1/1) J39/0481 (1/1) J39/0516 (2/2) J39/0532 (6/7) J39/0679 (1/1) J39/0714 (1/1) K38/0108 (1/85) K38/0111 (8/12) K38/0332 (1/1) K38/0637 (5/98) K39/0001 (2/2) K39/0066 (1/1) K39/0067 (1/1) K39/0068 (1/1) > 350 mg/L J39/0087 (1/1) J39/0121 (2/33)

Parameter	Drinking water MAV or GV* (MoH, 2008)	Stock water (ANZECC, 2000)	Irrigation water (ANZECC, 2000)
			J39/0232 (2/86) J39/0297 (1/1) K38/0111 (1/12) K39/0001 (1/2) K39/0066 (1/1) K39/0067 (1/1) K39/0068 (1/1) > 700 K39/0001 (1/2) K39/0066 (1/1) K39/0067 (1/1) K39/0068 (1/1)
E. coli (MPN/100 mL)	BY19/0026 (2/5) BZ19/0001 (1/1) BZ20/0019 (3/18) I37/0004 (1/13) I37/0012 (20/48) J37/0013 (6/26) J37/0017 (2/13) J37/0026 (6/13) J37/0033 (5/17) J37/0044 (13/56) J37/0073 (1/60) J37/0076 (2/2) J37/0077 (3/4) J37/0087 (9/62) J37/0092 (1/1) J37/0127 (1/1) J37/0201 (1/1) J37/0225 (2/4) J38/0045 (3/17) J38/0055 (7/13) J38/0068 (6/24) J38/0107 (3/5) J38/0125 (1/2) J38/0169 (12/38) J38/0171 (1/4) J38/0179 (1/2) J38/0181 (1/1) J38/0187 (14/47) J38/0214 (2/5) J38/0242 (18/76) J38/0280 (1/1) J38/0299 (1/1) J38/0360 (1/1) J38/0482 (4/13) J38/0623 (7/12) J38/0624 (1/13) J38/0625 (8/12)		

Parameter	Drinking water MAV or GV* (MoH, 2008)	Stock water (ANZECC, 2000)	Irrigation water (ANZECC, 2000)
	J38/0665 (3/10) J38/0752 (1/1) J38/0939 (1/1) J38/0946 (1/1) J39/0009 (1/33) J39/0012 (1/1) J39/0082 (1/1) J39/0093 (2/5) J39/0109 (2/18) J39/0121 (21/31) J39/0135 (25/104) J39/0181 (8/50) J39/0211 (4/6) J39/0232 (41/82) J39/0259 (1/69) J39/0261 (2/92) J39/0262 (1/1) J39/0294 (1/1) J39/0295 (1/1) J39/0297 (1/1) J39/0298 (1/1) J39/0304 (1/1) K37/0130 (23/48) K37/0281 (1/1) K37/0465 (7/38) K37/1065 (9/32) K37/1310 (6/26) K37/1335 (1/2) K37/1377 (11/31) K37/1381 (18/31) K37/1383 (9/31) K38/0105 (4/39) K38/0144 (7/90) K38/0148 (12/47) K38/0172 (8/42) K38/0240 (3/43) K38/0287 (4/10) K38/0296 (1/2) K38/0367 (12/47) K38/0371 (12/27) K38/0404 (12/46) K38/0406 (2/16) K38/0407 (2/17) K38/0408 (14/38) K38/0410 (3/10) K38/0430 (20/30) K38/0683 (1/1) K38/0720 (1/2) K38/0747 (32/50)		

Parameter	Drinking water MAV or GV* (MoH, 2008)	Stock water (ANZECC, 2000)	Irrigation water (ANZECC, 2000)
	K38/0760 (8/32) K38/0957 (3/10) K38/0979 (1/1) K38/1017 (7/45) K38/1078 (1/1) K38/1171 (2/2) K38/1301 (1/1) K38/1396 (3/4) K38/1800 (1/2) K38/1801 (1/2) K38/1802 (3/6) K38/1821 (5/7) K38/1995 (9/18) K38/2096 (16/23) K38/2210 (43/83) K38/2316 (1/19) K38/2331 (12/17) K39/0013 (3/8) K39/0020 (1/1) K39/0025 (2/13) K39/0033 (7/25) K39/0066 (1/1) K39/0067 (1/1)		
Faecal coliforms (cfu/100 mL)		≥ 100 Faecal coliforms J37/0026 (1/7) J37/0077 (1/3) J38/0019 (1/5) J38/0055 (1/11) J38/0169 (1/11) J38/0179 (1/13) J38/0482 (1/12) J38/0625 (2/11) J39/0082 (1/1) J39/0098 (1/1) J39/0121 (2/14) J39/0178 (1/1) J39/0210 (1/1) J39/0232 (1/37) J39/0295 (1/1) J39/0304 (1/1) K38/0105 (1/10) K38/0111 (3/12) K38/0472 (3/33) K38/0532 (1/1) K38/0747 (5/37) K38/2331 (2/18) K39/0013 (1/7) K39/0020 (1/1) K39/0066 (1/1) ≥ 100 E. coli	≥ 10 Faecal coliforms J37/0013 (2/7) J37/0026 (3/7) J37/0033 (1/3) J37/0044 (1/13) J37/0076 (1/1) J37/0077 (3/3) J38/0019 (1/5) J38/0055 (2/11) J38/0084 (1/3) J38/0130 (1/2) J38/0169 (1/11) J38/0179 (2/13) J38/0242 (1/6) J38/0482 (2/12) J38/0625 (2/11) J39/0082 (1/1) J39/0093 (1/8) J39/0095 (1/1) J39/0098 (1/1) J39/0121 (2/14) J39/0135 (2/34) J39/0151 (1/1) J39/0155 (1/1) J39/0161 (1/1) J39/0178 (1/1) J39/0189 (1/1) J39/0210 (1/1)

Parameter	Drinking water MAV or GV* (MoH, 2008)	Stock water (ANZECC, 2000)	Irrigation water (ANZECC, 2000)
		J37/0026 (1/13)	J39/0232 (4/37)
		J37/0077 (1/4)	J39/0295 (1/1)
		J37/0201 (1/1)	J39/0297 (1/1)
		J38/0045 (1/17)	J39/0298 (1/1)
		J38/0055 (3/13)	J39/0300 (1/1)
		J38/0242 (1/76)	J39/0304 (1/1)
		J38/0482 (1/13)	K38/0105 (1/10)
		J38/0625 (2/12)	K38/0106 (1/13)
		J39/0082 (1/1)	K38/0111 (3/12)
		J39/0121 (4/31)	K38/0356 (2/11)
		J39/0135 (1/104)	K38/0367 (2/33)
		J39/0232 (6/82)	K38/0371 (2/7)
		J39/0295 (1/1)	K38/0407 (1/11)
		J39/0297 (1/1)	K38/0427 (1/1)
		J39/0304 (1/1)	K38/0469 (4/34)
		K37/0130 (2/48)	K38/0472 (12/33)
		K37/1310 (1/26)	K38/0532 (1/1)
		K37/1381 (1/31)	K38/0747 (12/37)
		K38/0172 (1/42)	K38/1078 (1/3)
		K38/0410 (1/10)	K38/1372 (1/13)
		K38/0430 (1/30)	K38/2096 (3/11)
		K38/0747 (5/50)	K38/2331 (3/18)
		K38/1396 (1/4)	K39/0013 (1/7)
		K38/2210 (2/83)	K39/0020 (1/1)
		K38/2331 (1/17)	K39/0066 (1/1)
		K39/0020 (1/1)	
		K39/0033 (2/25)	
			≥ 10 *E. coli*
			BY19/0026 (2/5)
			BZ19/0001 (1/1)
			BZ20/0019 (3/18)
			I37/0004 (1/13)
			J37/0012 (20/48)
			J37/0013 (6/26)
			J37/0017 (2/13)
			J37/0026 (6/13)
			J37/0033 (5/17)
			J37/0044 (13/56)
			J37/0073 (1/60)
			J37/0076 (2/2)
			J37/0077 (3/4)
			J37/0087 (9/62)
			J37/0092 (1/1)
			J37/0127 (1/1)
			J37/0201 (1/1)
			J37/0225 (2/4)
			J38/0045 (3/17)
			J38/0055 (7/13)
			J38/0068 (6/24)
			J38/0107 (3/5)
			J38/0125 (1/2)
			J38/0169 (12/38)
			J38/0171 (1/4)
			J38/0179 (1/2)

Parameter	Drinking water MAV or GV* (MoH, 2008)	Stock water (ANZECC, 2000)	Irrigation water (ANZECC, 2000)
			J38/0181 (1/1) J38/0187 (14/47) J38/0214 (2/5) J38/0242 (18/76) J38/0280 (1/1) J38/0299 (1/1) J38/0360 (1/1) J38/0482 (4/13) J38/0623 (7/12) J38/0624 (1/13) J38/0625 (8/12) J38/0665 (3/10) J38/0752 (1/1) J38/0939 (1/1) J38/0946 (1/1) J39/0009 (1/33) J39/0012 (1/1) J39/0082 (1/1) J39/0093 (2/5) J39/0109 (2/18) J39/0121 (21/31) J39/0135 (25/104) J39/0181 (8/50) J39/0211 (4/6) J39/0232 (41/82) J39/0259 (1/69) J39/0261 (2/92) J39/0262 (1/1) J39/0294 (1/1) J39/0295 (1/1) J39/0297 (1/1) J39/0298 (1/1) J39/0304 (1/1) K37/0130 (23/48) K37/0281 (1/1) K37/0465 (7/38) K37/1065 (9/32) K37/1310 (6/26) K37/1335 (1/2) K37/1377 (11/31) K37/1381 (18/31) K37/1383 (9/31) K38/0105 (4/39) K38/0144 (7/90) K38/0148 (12/47) K38/0172 (8/42) K38/0240 (3/43) K38/0287 (4/10) K38/0296 (1/2) K38/0367 (12/47) K38/0371 (12/27) K38/0404 (12/46) K38/0406 (2/16) K38/0407 (2/17)

Parameter	Drinking water MAV or GV* (MoH, 2008)	Stock water (ANZECC, 2000)	Irrigation water (ANZECC, 2000)
			K38/0408 (14/38) K38/0410 (3/10) K38/0430 (20/30) K38/0683 (1/1) K38/0720 (1/2) K38/0747 (32/50) K38/0760 (8/32) K38/0957 (3/10) K38/0979 (1/1) K38/1017 (7/45) K38/1078 (1/1) K38/1171 (2/2) K38/1301 (1/1) K38/1396 (3/4) K38/1800 (1/2) K38/1801 (1/2) K38/1802 (3/6) K38/1821 (5/7) K38/1995 (9/18) K38/2096 (16/23) K38/2210 (43/83) K38/2316 (1/19) K38/2331 (12/17) K39/0013 (3/8) K39/0020 (1/1) K39/0025 (2/13) K39/0033 (7/25) K39/0066 (1/1) K39/0067 (1/1) ≥ 100 Faecal coliforms J37/0026 (1/7) J37/0077 (1/3) J38/0019 (1/5) J38/0055 (1/11) J38/0169 (1/11) J38/0179 (1/13) J38/0482 (1/12) J38/0625 (2/11) J39/0082 (1/1) J39/0098 (1/1) J39/0121 (2/14) J39/0178 (1/1) J39/0210 (1/1) J39/0232 (1/37) J39/0295 (1/1) J39/0304 (1/1) K38/0105 (1/10) K38/0111 (3/12) K38/0472 (3/33) K38/0532 (1/1) K38/0747 (5/37) K38/2331 (2/18) K39/0013 (1/7)

Parameter	Drinking water MAV or GV* (MoH, 2008)	Stock water (ANZECC, 2000)	Irrigation water (ANZECC, 2000)
			K39/0020 (1/1) K39/0066 (1/1) ≥ 100 *E. coli* J37/0026 (1/13) J37/0077 (1/4) J37/0201 (1/1) J38/0045 (1/17) J38/0055 (3/13) J38/0242 (1/76) J38/0482 (1/13) J38/0625 (2/12) J39/0082 (1/1) J39/0121 (4/31) J39/0135 (1/104) J39/0232 (6/82) J39/0295 (1/1) J39/0297 (1/1) J39/0304 (1/1) K37/0130 (2/48) K37/1310 (1/26) K37/1381 (1/31) K38/0172 (1/42) K38/0410 (1/10) K38/0430 (1/30) K38/0747 (5/50) K38/1396 (1/4) K38/2210 (2/83) K38/2331 (1/17) K39/0020 (1/1) K39/0033 (2/25) ≥ 1000 Faecal coliforms J38/0482 (1/12) J39/0082 (1/1) J39/0232 (1/37) K38/0472 (1/33) K38/0747 (1/37) K39/0020 (1/1) ≥ 1000 *E. coli* J38/0055 (2/13) J38/0482 (1/13) J39/0082 (1/1) J39/0121 (1/31) J39/0232 (3/82) K38/0172 (1/42) K38/0410 (1/10) K38/0430 (1/30) K38/0747 (1/50) K39/0020 (1/1) ≥ 10,000 Faecal coliforms K39/0020 (1/1)

Parameter	Drinking water MAV or GV* (MoH, 2008)	Stock water (ANZECC, 2000)	Irrigation water (ANZECC, 2000)
			≥ 10,000 *E. coli* None
Hardness (as CaCO3, mg/L)	J39/0012 (1/1) J39/0079 (1/1) J39/0082 (1/1) J39/0087 (1/1) J39/0089 (1/1) J39/0109 (5/27) J39/0121 (33/33) J39/0144 (1/1) J39/0168 (1/1) J39/0186 (1/1) J39/0189 (1/1) J39/0232 (42/4)8 J39/0259 (4/30) J39/0260 (1/1) J39/0261 (53/56) J39/0262 (1/1) J39/0297 (1/1) J39/0298 (1/1) J39/0299 (1/1) J39/0300 (1/1) J39/0301 (1/1) J39/0304 (1/1) J39/0516 (1/2) J39/0532 (6/6) J39/0663 (1/1) J39/0679 (1/1) J39/0686 (1/1) J39/0714 (1/1) K38/0108 (2/3) K38/0111 (6/8) K38/0172 (12/69) K38/0430 (1/57) K38/0473 (1/9) K38/0637 (2/3) K39/0001 (1/2) K39/0066 (1/1) K39/0067 (1/1) K39/0068 (1/1) K39/0258 (1/6)	< 60 (as CaCO3, mg/L) BY19/0013 (1/1) BY19/0026 (5/5) BY19/0029 (1/1) BY19/0040 (1/1) BY19/0045 (2/2) BZ18/0009 (1/1) BZ19/0116 (1/1) BZ19/0132 (1/1) I37/0001 (1/1) I37/0004 (17/17) J37/0010 (1/1) J37/0012 (42/54) J37/0013 (18/30) J37/0015 (1/1) J37/0017 (17/17) J37/0023 (1/1) J37/0026 (17/17) J37/0028 (1/1) J37/0031 (21/21) J37/0033 (17/17) J37/0044 (59/60) J37/0045 (1/1) J37/0053 (1/1) J37/0073 (18/61) J37/0076 (2/2) J37/0077 (4/4) J37/0087 (54/63) J37/0089 (1/2) J37/0090 (1/1) J37/0092 (1/1) J37/0127 (1/1) J37/0185 (1/1) J37/0189 (1/1) J37/0201 (1/1) J37/0213 (1/1) J37/0218 (2/2) J37/0225 (2/4) J37/0273 (1/1) J38/0004 (1/1) J38/0019 (16/18) J38/0023 (1/2) J38/0032 (1/1) J38/0037 (1/1) J38/0055 (1/19) J38/0068 (5/24) J38/0084 (4/5) J38/0107 (1/5) J38/0169 (11/45)	< 60 (as CaCO3, mg/L) BY19/0013 (1/1) BY19/0026 (5/5) BY19/0029 (1/1) BY19/0040 (1/1) BY19/0045 (2/2) BZ18/0009 (1/1) BZ19/0116 (1/1) BZ19/0132 (1/1) I37/0001 (1/1) I37/0004 (17/17) J37/0010 (1/1) J37/0012 (42/54) J37/0013 (18/30) J37/0015 (1/1) J37/0017 (17/17) J37/0023 (1/1) J37/0026 (17/17) J37/0028 (1/1) J37/0031 (21/21) J37/0033 (17/17) J37/0044 (59/60) J37/0045 (1/1) J37/0053 (1/1) J37/0073 (18/61) J37/0076 (2/2) J37/0077 (4/4) J37/0087 (54/63) J37/0089 (1/2) J37/0090 (1/1) J37/0092 (1/1) J37/0127 (1/1) J37/0185 (1/1) J37/0189 (1/1) J37/0201 (1/1) J37/0213 (1/1) J37/0218 (2/2) J37/0225 (2/4) J37/0273 (1/1) J38/0004 (1/1) J38/0019 (16/18) J38/0023 (1/2) J38/0032 (1/1) J38/0037 (1/1) J38/0055 (1/19) J38/0068 (5/24) J38/0084 (4/5) J38/0107 (1/5) J38/0169 (11/45)

Parameter	Drinking water MAV or GV* (MoH, 2008)	Stock water (ANZECC, 2000)	Irrigation water (ANZECC, 2000)
		J38/0171 (9/10)	J38/0171 (9/10)
		J38/0179 (7/8)	J38/0179 (7/8)
		J38/0181 (1/51)	J38/0181 (1/51)
		J38/0187 (50/51)	J38/0187 (50/51)
		J38/0214 (2/2)	J38/0214 (2/2)
		J38/0217 (2/5)	J38/0217 (2/5)
		J38/0242 (6/97)	J38/0242 (6/97)
		J38/0255 (26/26)	J38/0255 (26/26)
		J38/0259 (9/14)	J38/0259 (9/14)
		J38/0280 (1/1)	J38/0280 (1/1)
		J38/0374 (1/1)	J38/0374 (1/1)
		J38/0386 (1/1)	J38/0386 (1/1)
		J38/0465 (1/1)	J38/0465 (1/1)
		J38/0491 (1/1)	J38/0491 (1/1)
		J38/0619 (1/1)	J38/0619 (1/1)
		J38/0638 (1/1)	J38/0638 (1/1)
		J38/0893 (1/1)	J38/0893 (1/1)
		J38/0917 (1/1)	J38/0917 (1/1)
		J38/0939 (1/1)	J38/0939 (1/1)
		J38/0946 (1/1)	J38/0946 (1/1)
		J38/0963 (1/1)	J38/0963 (1/1)
		J39/0036 (1/1)	J39/0036 (1/1)
		J39/0039 (1/1)	J39/0039 (1/1)
		J39/0042 (1/1)	J39/0042 (1/1)
		J39/0043 (1/1)	J39/0043 (1/1)
		J39/0071 (1/1)	J39/0071 (1/1)
		J39/0080 (1/1)	J39/0080 (1/1)
		J39/0093 (2/10)	J39/0093 (2/10)
		J39/0102 (1/1)	J39/0102 (1/1)
		J39/0103 (1/1)	J39/0103 (1/1)
		J39/0105 (1/1)	J39/0105 (1/1)
		J39/0107 (1/1)	J39/0107 (1/1)
		J39/0134 (1/1)	J39/0134 (1/1)
		J39/0135 (11/67)	J39/0135 (11/67)
		J39/0146 (1/1)	J39/0146 (1/1)
		J39/0163 (1/1)	J39/0163 (1/1)
		J39/0166 (1/1)	J39/0166 (1/1)
		J39/0181 (24/54)	J39/0181 (24/54)
		J39/0184 (1/1)	J39/0184 (1/1)
		J39/0209 (1/1)	J39/0209 (1/1)
		J39/0210 (1/1)	J39/0210 (1/1)
		J39/0211 (1/10)	J39/0211 (1/10)
		J39/0215 (1/1)	J39/0215 (1/1)
		J39/0216 (1/1)	J39/0216 (1/1)
		J39/0232 (1/48)	J39/0232 (1/48)
		J39/0294 (1/1)	J39/0294 (1/1)
		J39/0481 (1/1)	J39/0481 (1/1)
		J39/0701 (1/1)	J39/0701 (1/1)
		J39/0705 (1/1)	J39/0705 (1/1)
		K37/0130 (22/23)	K37/0130 (22/23)
		K37/0465 (47/47)	K37/0465 (47/47)
		K37/0499 (1/1)	K37/0499 (1/1)
		K37/0500 (1/1)	K37/0500 (1/1)
		K37/0671 (1/1)	K37/0671 (1/1)

Parameter	Drinking water MAV or GV* (MoH, 2008)	Stock water (ANZECC, 2000)	Irrigation water (ANZECC, 2000)
		K37/0684 (1/1)	K37/0684 (1/1)
		K37/1311 (1/1)	K37/1311 (1/1)
		K37/1312 (1/1)	K37/1312 (1/1)
		K37/1335 (1/1)	K37/1335 (1/1)
		K37/1381 (1/1)	K37/1381 (1/1)
		K37/1640 (1/1)	K37/1640 (1/1)
		K37/2430 (1/1)	K37/2430 (1/1)
		K38/0041 (1/1)	K38/0041 (1/1)
		K38/0042 (4/5)	K38/0042 (4/5)
		K38/0044 (1/1)	K38/0044 (1/1)
		K38/0066 (1/1)	K38/0066 (1/1)
		K38/0087 (1/1)	K38/0087 (1/1)
		K38/0105 (5/47)	K38/0105 (5/47)
		K38/0106 (2/11)	K38/0106 (2/11)
		K38/0127 (2/8)	K38/0127 (2/8)
		K38/0135 (1/1)	K38/0135 (1/1)
		K38/0144 (22/93)	K38/0144 (22/93)
		K38/0148 (45/56)	K38/0148 (45/56)
		K38/0153 (1/1)	K38/0153 (1/1)
		K38/0165 (1/1)	K38/0165 (1/1)
		K38/0174 (2/2)	K38/0174 (2/2)
		K38/0202 (1/1)	K38/0202 (1/1)
		K38/0231 (1/2)	K38/0231 (1/2)
		K38/0240 (46/51)	K38/0240 (46/51)
		K38/0254 (1/2)	K38/0254 (1/2)
		K38/0264 (7/7)	K38/0264 (7/7)
		K38/0268 (9/17)	K38/0268 (9/17)
		K38/0287 (14/16)	K38/0287 (14/16)
		K38/0356 (6/10)	K38/0356 (6/10)
		K38/0360 (1/1)	K38/0360 (1/1)
		K38/0383 (8/8)	K38/0383 (8/8)
		K38/0404 (10/55)	K38/0404 (10/55)
		K38/0406 (12/21)	K38/0406 (12/21)
		K38/0407 (23/23)	K38/0407 (23/23)
		K38/0408 (47/47)	K38/0408 (47/47)
		K38/0409 (2/3)	K38/0409 (2/3)
		K38/0410 (15/16)	K38/0410 (15/16)
		K38/0430 (1/57)	K38/0430 (1/57)
		K38/0459 (14/14)	K38/0459 (14/14)
		K38/0473 (2/9)	K38/0473 (2/9)
		K38/0490 (1/1)	K38/0490 (1/1)
		K38/0491 (1/1)	K38/0491 (1/1)
		K38/0494 (1/1)	K38/0494 (1/1)
		K38/0500 (1/1)	K38/0500 (1/1)
		K38/0503 (1/1)	K38/0503 (1/1)
		K38/0511 (1/1)	K38/0511 (1/1)
		K38/0520 (1/1)	K38/0520 (1/1)
		K38/0522 (1/1)	K38/0522 (1/1)
		K38/0528 (1/1)	K38/0528 (1/1)
		K38/0529 (1/1)	K38/0529 (1/1)
		K38/0531 (1/1)	K38/0531 (1/1)
		K38/0532 (1/1)	K38/0532 (1/1)
		K38/0604 (1/1)	K38/0604 (1/1)
		K38/0680 (1/1)	K38/0680 (1/1)

Parameter	Drinking water MAV or GV* (MoH, 2008)	Stock water (ANZECC, 2000)	Irrigation water (ANZECC, 2000)
		K38/0683 (1/1)	K38/0683 (1/1)
		K38/0690 (17/17)	K38/0690 (17/17)
		K38/0698 (1/1)	K38/0698 (1/1)
		K38/0712 (1/1)	K38/0712 (1/1)
		K38/0715 (1/1)	K38/0715 (1/1)
		K38/0720 (1/1)	K38/0720 (1/1)
		K38/0795 (1/1)	K38/0795 (1/1)
		K38/0840 (1/1)	K38/0840 (1/1)
		K38/0850 (1/1)	K38/0850 (1/1)
		K38/0852 (1/1)	K38/0852 (1/1)
		K38/0860 (1/1)	K38/0860 (1/1)
		K38/0861 (1/1)	K38/0861 (1/1)
		K38/0950 (1/1)	K38/0950 (1/1)
		K38/0980 (1/1)	K38/0980 (1/1)
		K38/1017 (8/48)	K38/1017 (8/48)
		K38/1075 (1/2)	K38/1075 (1/2)
		K38/1077 (2/2)	K38/1077 (2/2)
		K38/1081 (2/3)	K38/1081 (2/3)
		K38/1097 (1/1)	K38/1097 (1/1)
		K38/1230 (1/1)	K38/1230 (1/1)
		K38/1301 (1/1)	K38/1301 (1/1)
		K38/1302 (1/1)	K38/1302 (1/1)
		K38/1316 (2/2)	K38/1316 (2/2)
		K38/1334 (1/1)	K38/1334 (1/1)
		K38/1354 (2/2)	K38/1354 (2/2)
		K38/1358 (1/1)	K38/1358 (1/1)
		K38/1366 (1/1)	K38/1366 (1/1)
		K38/1372 (4/9)	K38/1372 (4/9)
		K38/1433 (1/1)	K38/1433 (1/1)
		K38/1443 (1/1)	K38/1443 (1/1)
		K38/1512 (1/1)	K38/1512 (1/1)
		K38/1540 (1/1)	K38/1540 (1/1)
		K38/1691 (1/1)	K38/1691 (1/1)
		K38/1704 (1/1)	K38/1704 (1/1)
		K38/1705 (1/1)	K38/1705 (1/1)
		K38/1706 (8/9)	K38/1706 (8/9)
		K38/1776 (3/3)	K38/1776 (3/3)
		K38/1777 (1/1)	K38/1777 (1/1)
		K38/1821 (1/8)	K38/1821 (1/8)
		K38/1869 (1/1)	K38/1869 (1/1)
		K38/2163 (1/1)	K38/2163 (1/1)
		K38/2270 (1/1)	K38/2270 (1/1)
		K38/2273 (1/1)	K38/2273 (1/1)
		K38/2316 (19/20)	K38/2316 (19/20)
		K38/2329 (1//1)	K38/2329 (1//1)
		K39/0013 (9/12)	K39/0013 (9/12)
		K39/0025 (9/13)	K39/0025 (9/13)
		K39/0027 (1/1)	K39/0027 (1/1)
		K39/0033 (11/29)	K39/0033 (11/29)
		> 350 (as CaCO3, mg/L)	> 350 (as CaCO3, mg/L)
		J39/0087 (1/1)	J39/0087 (1/1)
		J39/0089 (1/1)	J39/0089 (1/1)
		J39/0121 (17/33)	J39/0121 (17/33)

Parameter	Drinking water MAV or GV* (MoH, 2008)	Stock water (ANZECC, 2000)	Irrigation water (ANZECC, 2000)
		J39/0168 (1/1) J39/0186 (1/1) J39/0232 (3/48) J39/0297 (1/1) J39/0298 (1/1) K38/0111 (5/8) K38/0172 (5/69) K39/0001 (1/2) K39/0066 (1/1) K39/0067 (1/1) K39/0068 (1/1)	J39/0168 (1/1) J39/0186 (1/1) J39/0232 (3/48) J39/0297 (1/1) J39/0298 (1/1) K38/0111 (5/8) K38/0172 (5/69) K39/0001 (1/2) K39/0066 (1/1) K39/0067 (1/1) K39/0068 (1/1)
Iron	> 0.2 BY19/0013 (2/2) J37/0202 (1/2) J38/0040 (1/2) J38/0068 (1/14) J38/0187 (1/26) J38/0214 (1/2) J38/0242 (1/24) J38/0283 (1/1) J38/0889 (1/9) J39/0009 (1/40) J39/0090 (2/13) J39/0109 (4/84) J39/0121 (12/17) J39/0137 (1/1) J39/0211 (1/9) J39/0232 (1/16) J39/0259 (9/22) J39/0398 (1/1) J39/0412 (1/8) J39/0481 (1/1) J39/0516 (1/2) J39/0532 (9/9) J39/0705 (1/1) K38/0065 (1/1) K38/0105 (3/20) K38/0108 (1/1) K38/0240 (1/16) K38/0430 (1/16) K38/0637 (2/2) K38/0698 (1/3) K38/1073 (1/1) K38/1379 (1/1) K38/1380 (1/1) K38/1381 (1/1) K39/0001 (1/2) K39/0006 (1/17)		> 0.2 mg/L BY19/0013 (2/2) J37/0202 (1/2) J38/0040 (1/2) J38/0068 (1/14) J38/0187 (1/26) J38/0214 (1/2) J38/0242 (1/24) J38/0283 (1/1) J38/0889 (1/9) J39/0009 (1/40) J39/0090 (2/13) J39/0109 (4/84) J39/0121 (12/17) J39/0137 (1/1) J39/0211 (1/9) J39/0232 (1/16) J39/0259 (9/22) J39/0398 (1/1) J39/0412 (1/8) J39/0481 (1/1) J39/0516 (1/2) J39/0532 (9/9) J39/0705 (1/1) K38/0065 (1/1) K38/0105 (3/20) K38/0108 (1/1) K38/0240 (1/16) K38/0430 (1/16) K38/0637 (2/2) K38/0698 (1/3) K38/1073 (1/1) K38/1379 (1/1) K38/1380 (1/1) K38/1381 (1/1) K39/0001 (1/2) K39/0006 (1/17)
Manganese (mg/L)	> 0.4 mg/L J37/0012 (1/18) J38/0259 (1/16) J38/0283 (1/1)		> 0.2 mg/L J37/0012 (1/18) J38/0040 (1/1) J38/0068 (1/15)

Parameter	Drinking water MAV or GV* (MoH, 2008)	Stock water (ANZECC, 2000)	Irrigation water (ANZECC, 2000)
	J39/0121 (3/28) J39/0232 (5/19) J39/0663 (1/1) K38/0108 (1/1) K38/0172 (6/27) K39/0001 (1/2) >0.1 mg/L J37/0012 (1/18) J37/0202 (2/2) J38/0040 (1/1) J38/0068 (1/15) J38/0214 (1/2) J38/0259 (2/16) J38/0283 (1/1) J38/0933 (1/1) J39/0009 (1/42) J39/0082 (1/1) J39/0121 (13/28) J39/0137 (1/1) J39/0193 (1/1) J39/0232 (15/19) J39/0259 (5/32) J39/0299 (2/2) J39/0304 (1/1) J39/0441 (1/1) J39/0442 (1/1) J39/0523 (1/1) J39/0663 (1/1) J39/0719 (1/1) K37/0500 (1/1) K37/1311 (1/1) K38/0108 (1/1) K38/0172 (16/27) K39/0001 (1/2) K39/0020 (1/1) K39/0025 (1/12) >0.04 mg/L CA19/0009 (1/1) J37/0012 (1/18) J37/0089 (1/2) J37/0202 (2/2) J37/0225 (2/2) J38/0040 (1/1) J38/0055 (1/13) J38/0068 (3/15) J38/0214 (1/2) J38/0259 (14/16) J38/0283 (1/1) J38/0491 (1/1) J38/0933 (1/1) J39/0009 (39/42) J39/0010 (1/1)		J38/0259 (1/16) J38/0283 (1/1) J39/0082 (1/1) J39/0121 (8/28) J39/0232 (8/19) J39/0663 (1/1) J39/0719 (1/1) K38/0108 (1/1) K38/0172 (12/27) K39/0001 (1/2) K39/0020 (1/1)

Parameter	Drinking water MAV or GV* (MoH, 2008)	Stock water (ANZECC, 2000)	Irrigation water (ANZECC, 2000)
	J39/0082 (1/1) J39/0090 (2/15) J39/0121 (19/28) J39/0137 (1/1) J39/0181 (1/30) J39/0193 (1/1) J39/0232 (16/19) J39/0259 (29/32) J39/0261 (1/32) J39/0294 (1/1) J39/0295 (1/1) J39/0299 (2/2) J39/0300 (1/1) J39/0304 (1/1) J39/0441 (1/1) J39/0442 (1/1) J39/0489 (1/1) J39/0523 (1/1) J39/0663 (1/1) J39/0669 (1/1) J39/0701 (1/1) J39/0705 (1/1) J39/0719 (1/1) J39/0904 (1/1) K37/0500 (1/1) K37/1311 (1/1) K38/0065 (1/1) K38/0108 (1/1) K38/0172 (21/27) K38/0255 (1/1) K38/0406 (1/17) K38/0407 (1/18) K38/0637 (1/1) K39/0001 (2/2) K39/0020 (1/1) K39/0025 (1/12)		
Nitrate-N (mg/L)	J37/0013 (6/30) J37/0044 (2/59) J37/0068 (1/1) J37/0073 (54/61) J37/0087 (3/62) J37/0089 (1/2) J37/0164 (1/1) J38/0019 (1/19) J38/0068 (1/24) J38/0169 (1/46) J38/0171 (1/12) J38/0194 (1/1) J38/0242 (4/99) J38/0299 (1/1) J39/0178 (1/1) J39/0298 (1/1) K38/0015 (1/1)	None	

Parameter	Drinking water MAV or GV* (MoH, 2008)	Stock water (ANZECC, 2000)	Irrigation water (ANZECC, 2000)
	K38/0088 (3/4) K38/0106 (6/69) K38/0108 (30/85) K38/0127 (4/10) K38/0144 (10/93) K38/0172 (50/82) K38/0296 (2/2) K38/0356 (41/121) K38/0367 (9/47) K38/0371 (28/31) K38/0404 (20/56) K38/0409 (1/20) K38/0424 (1/2) K38/0426 (3/8) K38/0430 (20/67) K38/0473 (1/54) K38/0637 (24/2) K38/0689 (3/5) K38/0698 (42/68) K38/0747 (25/52) K38/0957 (31/110) K38/1017 (3/47) K38/1075 (35/78) K38/1079 (34/55) K38/1081 (14/47) K38/1372 (5/33) K38/1396 (4/4) K38/1800 (2/3) K38/1801 (3/3) K38/1802 (7/7) K38/1995 (18/18) K38/2096 (15/24) K38/2210 (10/84) K38/2331 (15/18) K39/0013 (4/14) K39/0033 (8/30)		
pH (lab)	< 7.0 BY19/0026 (2/5) BY19/0029 (1/1) BY19/0040 (1/1) BY19/0045 (1/2) BZ19/0015 (1/1) I37/0001 (1/1) I37/0004 (15/17) J37/0010 (1/1) J37/0012 (55/57) J37/0013 (30/30) J37/0015 (1/1) J37/0017 (17/17) J37/0023 (1/1) J37/0026 (17/17) J37/0031 (21/21) J37/0033 (6/17)	< 6.0 J37/0010 (1/1) J37/0012 (1/57) J37/0013 (14/30) J37/0017 (10/17) J37/0023 (1/1) J37/0031 (5/21) J37/0044 (27/60) J37/0073 (1/61) J37/0087 (10/63) J37/0164 (1/1) J38/0019 (2/19) J38/0107 (1/5) J38/0187 (9/51) J39/0109 (1/84) J39/0232 (1/86) K38/0172 (28/80)	< 6.0 J37/0010 (1/1) J37/0012 (1/57) J37/0013 (14/30) J37/0017 (10/17) J37/0023 (1/1) J37/0031 (5/21) J37/0044 (27/60) J37/0073 (1/61) J37/0087 (10/63) J37/0164 (1/1) J38/0019 (2/19) J38/0107 (1/5) J38/0187 (9/51) J39/0109 (1/84) J39/0232 (1/86) K38/0172 (28/80)

Parameter	Drinking water MAV or GV* (MoH, 2008)	Stock water (ANZECC, 2000)	Irrigation water (ANZECC, 2000)
	J37/0044 (53/60)	K38/0426 (1/5)	K38/0426 (1/5)
	J37/0053 (1/1)	K38/0430 (24/67)	K38/0430 (24/67)
	J37/0068 (1/1)	K38/0472 (1/33)	K38/0472 (1/33)
	J37/0073 (58/61)	K39/0025 (1/13)	K39/0025 (1/13)
	J37/0076 (1/2)	K39/0033 (1/29)	K39/0033 (1/29)
	J37/0077 (4/4)		
	J37/0087 (62/63)	>8.5	>8.5
	J37/0089 (2/2)	K38/0264 (1/9)	K38/0264 (1/9)
	J37/0090 (1/1)	K38/0383 (1/11)	K38/0383 (1/11)
	J37/0127 (1/1)	K38/1081 (9/47)	K38/1081 (9/47)
	J37/0164 (1/1)	K38/1707 (1/1)	K38/1707 (1/1)
	J37/0213 (1/1)	K38/2377 (1/1)	K38/2377 (1/1)
	J37/0218 (2/2)		
	J37/0225 (4/4)		
	J37/0273 (1/1)		
	J38/0019 (19/19)		
	J38/0023 (6/6)		
	J38/0028 (3/4)		
	J38/0030 (1/1)		
	J38/0032 (2/2)		
	J38/0045 (17/25)		
	J38/0053 (1/1)		
	J38/0055 (19/21)		
	J38/0068 (23/24)		
	J38/0084 (14/14)		
	J38/0085 (2/2)		
	J38/0088 (1/1)		
	J38/0107 (5/5)		
	J38/0125 (3/10)		
	J38/0130 (1/2)		
	J38/0146 (1/1)		
	J38/0149 (1/1)		
	J38/0159 (1/1)		
	J38/0169 (44/47)		
	J38/0170 (3/3)		
	J38/0171 (12/12)		
	J38/0179 (11/13)		
	J38/0182 (1/1)		
	J38/0187 (51/51)		
	J38/0188 (1/1)		
	J38/0194 (1/1)		
	J38/0214 (1/2)		
	J38/0217 (2/5)		
	J38/0242 (90/100)		
	J38/0255 (2/26)		
	J38/0259 (10/15)		
	J38/0440 (1/1)		
	J38/0939 (1/1)		
	J39/0036 (1/1)		
	J39/0039 (1/1)		
	J39/0042 (1/1)		
	J39/0043 (1/1)		
	J39/0063 (1/1)		
	J39/0068 (1/1)		

Parameter	Drinking water MAV or GV* (MoH, 2008)	Stock water (ANZECC, 2000)	Irrigation water (ANZECC, 2000)
	J39/0071 (1/1) J39/0079 (1/1) J39/0083 (1/1) J39/0084 (1/1) J39/0089 (1/1) J39/0090 (11/21) J39/0093 (10/10) J39/0095 (1/1) J39/0097 (1/1) J39/0102 (1/1) J39/0103 (1/1) J39/0104 (1/1) J39/0105 (1/1) J39/0106 (1/1) J39/0107 (1/1) J39/0109 (15/84) J39/0121 (22/33) J39/0134 (2/2) J39/0135 (86/107) J39/0144 (1/1) J39/0146 (1/1) J39/0151 (1/1) J39/0152 (1/1) J39/0154 (1/1) J39/0158 (1/1) J39/0161 (1/1) J39/0163 (1/1) J39/0166 (1/1) J39/0181 (42/54) J39/0184 (1/1) J39/0186 (1/1) J39/0189 (1/1) J39/0209 (1/1) J39/0210 (1/1) J39/0211 (6/10) J39/0215 (1/1) J39/0216 (1/1) J39/0227 (1/1) J39/0232 (81/86) J39/0259 (3/69) J39/0261 (78/94) J39/0294 (1/1) J39/0295 (1/1) J39/0301 (1/1) J39/0388 (1/1) J39/0490 (1/1) J39/0516 (1/2) K37/0130 (21/25) K37/0465 (48/49) K37/0499 (1/1) K37/0500 (1/1) K37/0671 (6/6) K37/0684 (1/1) K37/1335 (1/1)		

Parameter	Drinking water MAV or GV* (MoH, 2008)	Stock water (ANZECC, 2000)	Irrigation water (ANZECC, 2000)
	K37/2430 (1/1) K38/0015 (1/1) K38/0037 (1/1) K38/0042 (1/6) K38/0088 (1/1) K38/0089 (1/1) K38/0105 (6/50) K38/0106 (66/67) K38/0108 (65/76) K38/0111 (4/21) K38/0120 (1/1) K38/0127 (9/10) K38/0135 (1/1) K38/0144 (43/93) K38/0148 (53/58) K38/0153 (1/1) K38/0164 (1/1) K38/0165 (1/2) K38/0171 (1/1) K38/0172 (79/80) K38/0174 (3/3) K38/0180 (1/1) K38/0185 (2/2) K38/0222 (1/1) K38/0231 (8/42) K38/0240 (37/53) K38/0253 (9/10) K38/0254 (32/32) K38/0255 (11/14) K38/0264 (1/9) K38/0268 (26/27) K38/0274 (1/1) K38/0278 (1/1) K38/0287 (15/18) K38/0296 (1/1) K38/0332 (1/1) K38/0340 (1/1) K38/0347 (1/1) K38/0356 (91/111) K38/0360 (1/1) K38/0367 (34/39) K38/0371 (19/23) K38/0404 (45/56) K38/0406 (18/23) K38/0407 (23/25) K38/0408 (39/49) K38/0409 (16/19) K38/0410 (13/18) K38/0424 (2/2) K38/0425 (1/1) K38/0426 (5/5) K38/0427 (2/2) K38/0430 (65/67) K38/0431 (4/4)		

Parameter	Drinking water MAV or GV* (MoH, 2008)	Stock water (ANZECC, 2000)	Irrigation water (ANZECC, 2000)
	K38/0434 (1/1) K38/0435 (1/1) K38/0436 (1/1) K38/0437 (2/2) K38/0441 (1/1) K38/0449 (1/1) K38/0450 (1/1) K38/0468 (26/33) K38/0469 (32/33) K38/0472 (26/33) K38/0473 (14/54) K38/0490 (1/1) K38/0492 (2/2) K38/0493 (2/2) K38/0494 (2/2) K38/0495 (2/2) K38/0496 (3/3) K38/0497 (1/1) K38/0498 (1/1) K38/0499 (2/2) K38/0500 (2/2) K38/0501 (2/2) K38/0502 (2/2) K38/0503 (2/2) K38/0504 (2/2) K38/0505 (2/2) K38/0506 (2/2) K38/0507 (2/2) K38/0508 (2/2) K38/0509 (1/1) K38/0510 (2/2) K38/0511 (2/2) K38/0512 (2/2) K38/0513 (2/2) K38/0514 (2/2) K38/0515 (1/1) K38/0516 (1/1) K38/0518 (2/2) K38/0519 (2/2) K38/0520 (2/2) K38/0521 (2/2) K38/0522 (2/2) K38/0523 (2/2) K38/0524 (1/1) K38/0525 (1/1) K38/0526 (2/2) K38/0527 (1/1) K38/0528 (2/2) K38/0529 (2/2) K38/0530 (2/2) K38/0531 (2/2) K38/0532 (1/1) K38/0538 (2/2) K38/0539 (1/1)		

Parameter	Drinking water MAV or GV* (MoH, 2008)	Stock water (ANZECC, 2000)	Irrigation water (ANZECC, 2000)
	K38/0540 (1/1)		
	K38/0637 (47/89)		
	K38/0680 (1/1)		
	K38/0683 (1/1)		
	K38/0698 (34/63)		
	K38/0712 (1/1)		
	K38/0747 (41/44)		
	K38/0760 (4/26)		
	K38/0819 (7/7)		
	K38/0840 (1/1)		
	K38/0852 (1/1)		
	K38/0861 (1/1)		
	K38/0950 (7/8)		
	K38/0957 (92/101)		
	K38/0979 (1/1)		
	K38/0980 (1/1)		
	K38/1017 (41/48)		
	K38/1073 (1/2)		
	K38/1075 (51/69)		
	K38/1077 (11/29)		
	K38/1078 (99/102)		
	K38/1079 (40/47)		
	K38/1081 (22/47)		
	K38/1171 (2/2)		
	K38/1230 (2/2)		
	K38/1298 (1/1)		
	K38/1301 (1/1)		
	K38/1302 (1/1)		
	K38/1314 (1/1)		
	K38/1357 (1/1)		
	K38/1358 (1/1)		
	K38/1372 (30/31)		
	K38/1380 (1/1)		
	K38/1381 (1/1)		
	K38/1443 (2/2)		
	K38/1800 (1/1)		
	K38/1801 (1/1)		
	K38/1802 (1/1)		
	K38/1821 (1/8)		
	K38/1861 (1/1)		
	K38/2096 (16/17)		
	K38/2154 (1/1)		
	K38/2155 (1/1)		
	K38/2210 (63/84)		
	K38/2270 (1/1)		
	K38/2273 (1/1)		
	K38/2316 (12/20)		
	K38/2331 (15/18)		
	K39/0001 (1/2)		
	K39/0006 (13/21)		
	K39/0013 (12/12)		
	K39/0020 (1/1)		
	K39/0025 (12/13)		
	K39/0027 (1/1)		

Parameter	Drinking water MAV or GV* (MoH, 2008)	Stock water (ANZECC, 2000)	Irrigation water (ANZECC, 2000)
	K39/0028 (1/1) K39/0033 (21/29) K39/0066 (1/1) K39/0067 (1/1) K39/0068 (1/1) K39/0257 (1/1) K39/0258 (1/7) > 8.5 K38/0264 (1/9) K38/0383 (1/11) K38/1081 (9/47) K38/1707 (1/1) K38/2377 (1/1)		
Sodium (mg/L)	J39/0297 (1/1) J39/0481 (1/1) K39/0001 (1/2) K39/0066 (1/1) K39/0067 (1/1) K39/0068 (1/1)	-	> 115 mg/L J39/0012 (1/1) J39/0079 (1/1) J39/0082 (1/1) J39/0087 (1/1) J39/0089 (1/1) J39/0121 (2/33) J39/0186 (1/1) J39/0232 (2/48) J39/0260 (1/1) J39/0261 (12/56) J39/0297 (1/1) J39/0298 (1/1) J39/0299 (1/1) J39/0481 (1/1) K39/0001 (2/2) K39/0066 (1/1) K39/0067 (1/1) K39/0068 (1/) > 230 mg/L J39/0297 (1/1) J39/0481 (1/1) K39/0001 (1/2) K39/0066 (1/1) K39/0067 (1/1) K39/0068 (1/1) > 460 mg/L J39/0481 (1/1) K39/0001 (1/2) K39/0066 (1/1) K39/0067 (1/1) K39/0068 (1/1)

Parameter	Drinking water MAV or GV* (MoH, 2008)	Stock water (ANZECC, 2000)	Irrigation water (ANZECC, 2000)
Sulphate (mg/L)	K38/0172 (7/82) K39/0067 (1/1) K39/0068 (1/1)	> 1,000 mg/L K39/0068 (1/1) > 2000 mg/L None	-
TDS (mg/L) / EC (mS/m)	> 168 mS/m J39/0087 (1/1) J39/0121 (1/33) J39/0297 (1/1) J39/0481 (1/1) K39/0001 (1/2) K39/0066 (1/1) K39/0067 (1/1) K39/0068 (1/1)	> 504 mS/m K39/0066 (1/1) K39/0067 (1/1) K39/0068 (1/1) > 672 mS/m K39/0066 (1/1) K39/0067 (1/1) K39/0068 (1/1) > 840 mS/m K39/0066 (1/1) K39/0067 (1/1) K39/0068 (1/1) > 1,681 mS/m K39/0068 (1/1)	> 69 mS/m J38/0040 (1/1) J38/0615 (1/1) J39/0012 (1/1) J39/0079 (1/1) J39/0082 (1/1) J39/0087 (1/1) J39/0089 (1/1) J39/0121 (32/33) J39/0137 (1/1) J39/0168 (1/1) J39/0178 (1/1) J39/0186 (1/1) J39/0232 (77/86) J39/0259 (69/69) J39/0260 (1/1) J39/0261 (92/94) J39/0262 (1/1) J39/0297 (1/1) J39/0298 (1/1) J39/0299 (1/1) J39/0300 (1/1) J39/0301 (1/1) J39/0304 (1/1) 39/0388 (1/1) J39/0481 (1/1) J39/0516 (2/2) J39/0523 (1/1) J39/0532 (7/7) J39/0663 (1/1) J39/0679 (1/1) J39/0686 (1/1) J39/0714 (1/1) K38/0108 (16/84) K38/0111 (14/21) K38/0172 (13/79) K38/0254 (1/32) K38/0332 (1/1) K38/0356 (2/119) K38/0473 (1/54) K38/0637 (33/96) K38/0698 (4/66) K38/1079 (1/54) K39/0001 (2/2) K39/0020 (1/1) K39/0066 (1/1) K39/0067 (1/1) K39/0068 (1/1)

Parameter	Drinking water MAV or GV* (MoH, 2008)	Stock water (ANZECC, 2000)	Irrigation water (ANZECC, 2000)
			K39/0257 (1/1) > 138 mS/m J39/0079 (1/1) J39/0087 (1/1) J39/0089 (1/1) J39/0121 (6/33) J39/0232 (3/86) J39/0261 (1/94) J39/0297 (1/1) J39/0298 (1/1) J39/0481 (1/1) K38/0172 (2/79) K38/0254 (1/32) K39/0001 (1/2) K39/0066 (1/1) K39/0067 (1/1) K39/0068 (1/1) > 327 mS/m K39/0001 (1/2) K39/0066 (1/1) K39/0067 (1/1) K39/0068 (1/1) > 559 mS/m K39/0066 (1/1) K39/0067 (1/1) K39/0068 (1/1) > 886 mS/m K39/0066 (1/1) K39/0067 (1/1) K39/0068 (1/1)

Appendix D Wells potentially affected by seawater intrusion

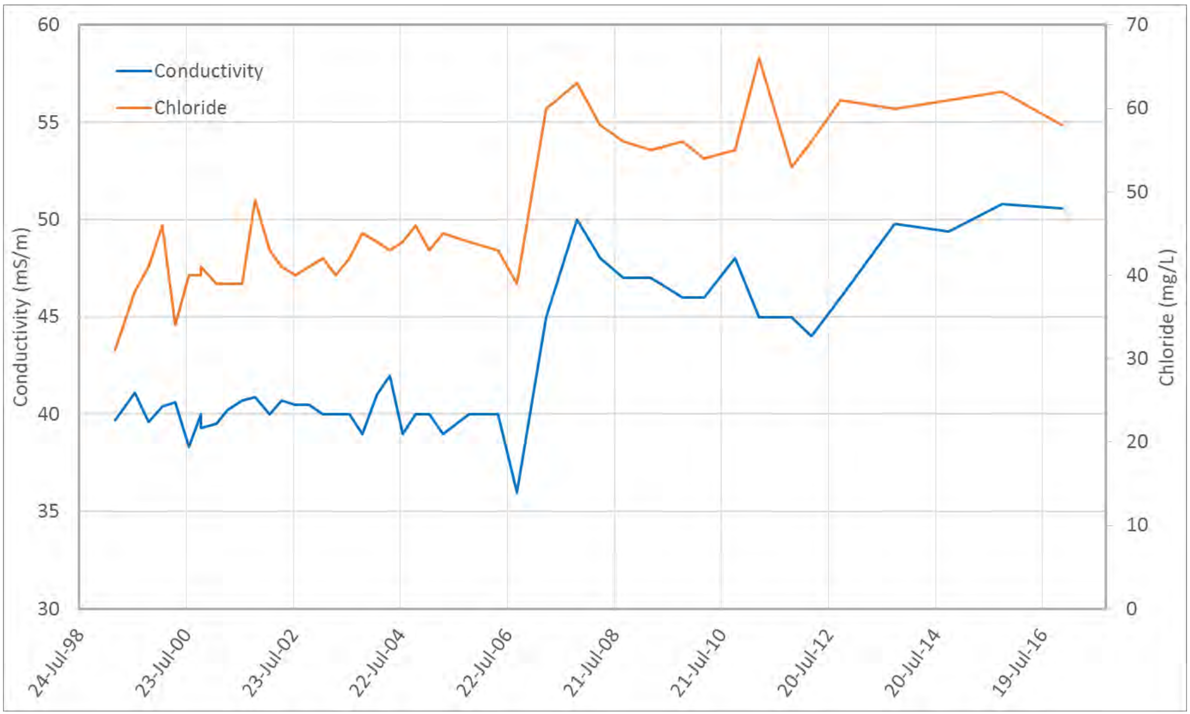

Figure D-1: Trend for conductivity and chloride concentrations in well J39/0009 located near the Pareora River

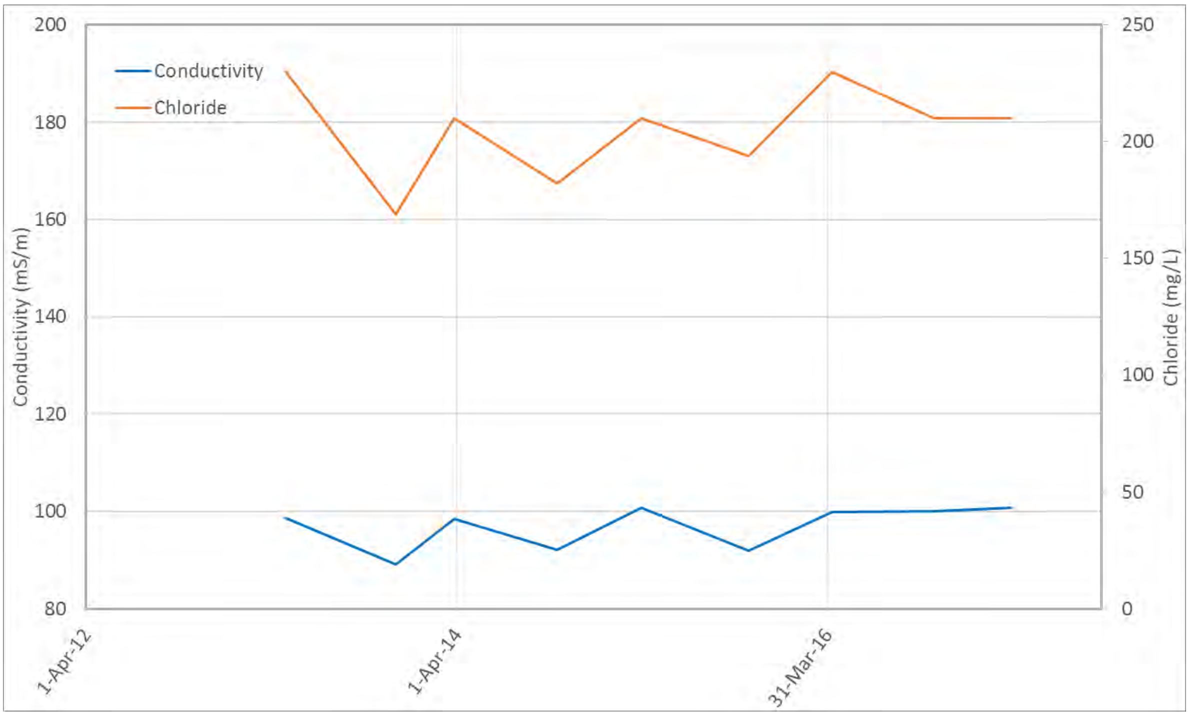

Figure D-2: Trend for conductivity and chloride concentrations in well J39/0532 located just north of St Andrews

Appendix E Trends in nitrate-N concentrations

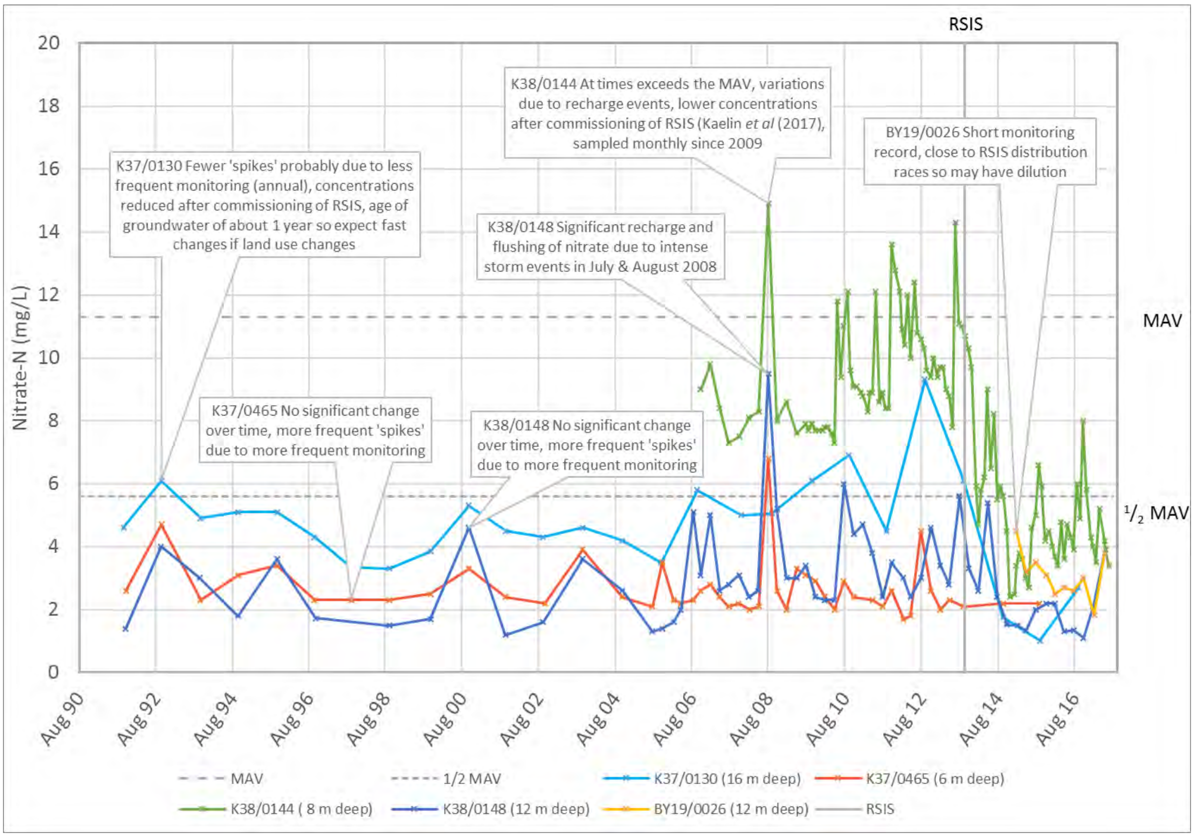

Figure E-1: Nitrate-N trends for long-term monitoring wells in the upper part of the Rangitata-Orton province

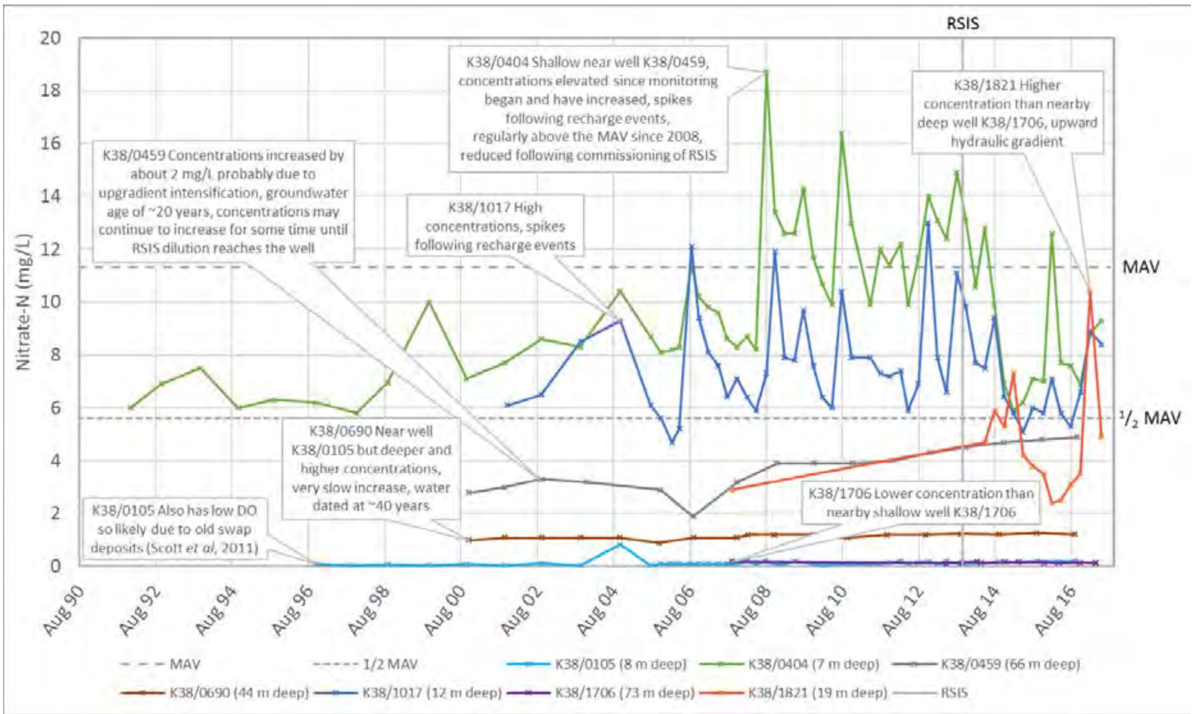

Figure E-2: Nitrate-N trends for long-term monitoring wells in the lower part of the Rangitata-Orton province

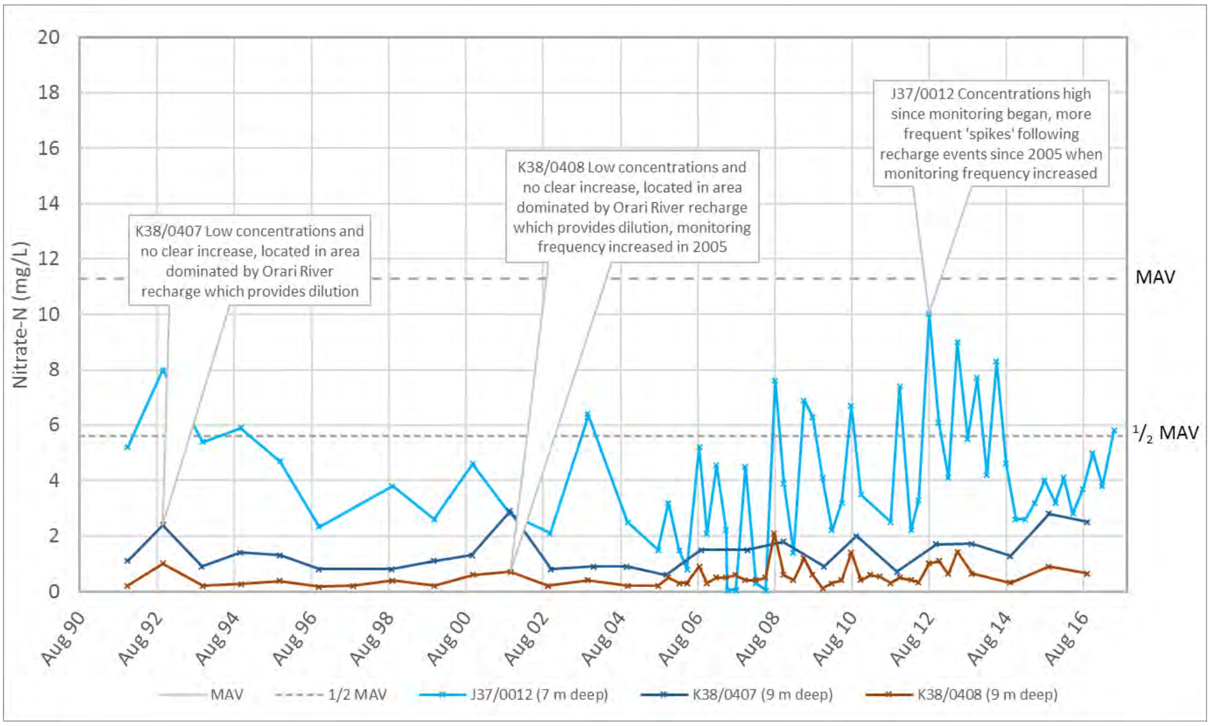

Figure E-3: Nitrate-N trends for long-term monitoring wells in the upper and middle parts of the Orari province

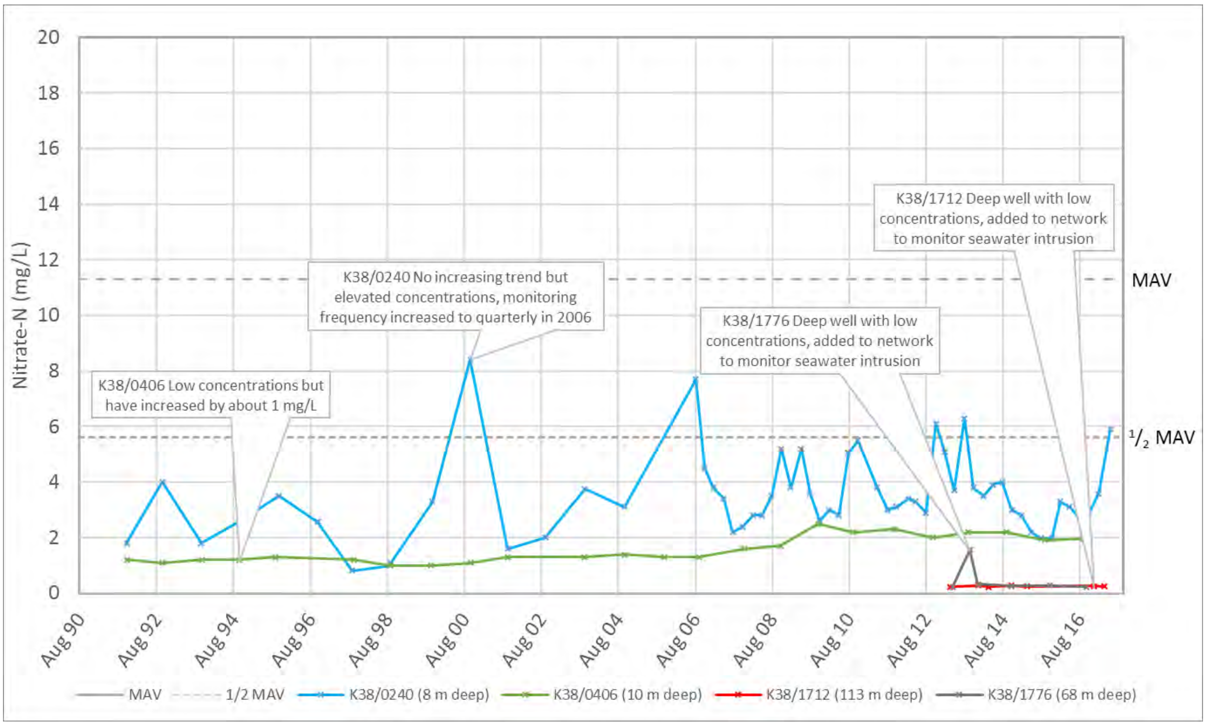

Figure E-4: Nitrate-N trends for long-term monitoring wells in the lower parts of the Orari province

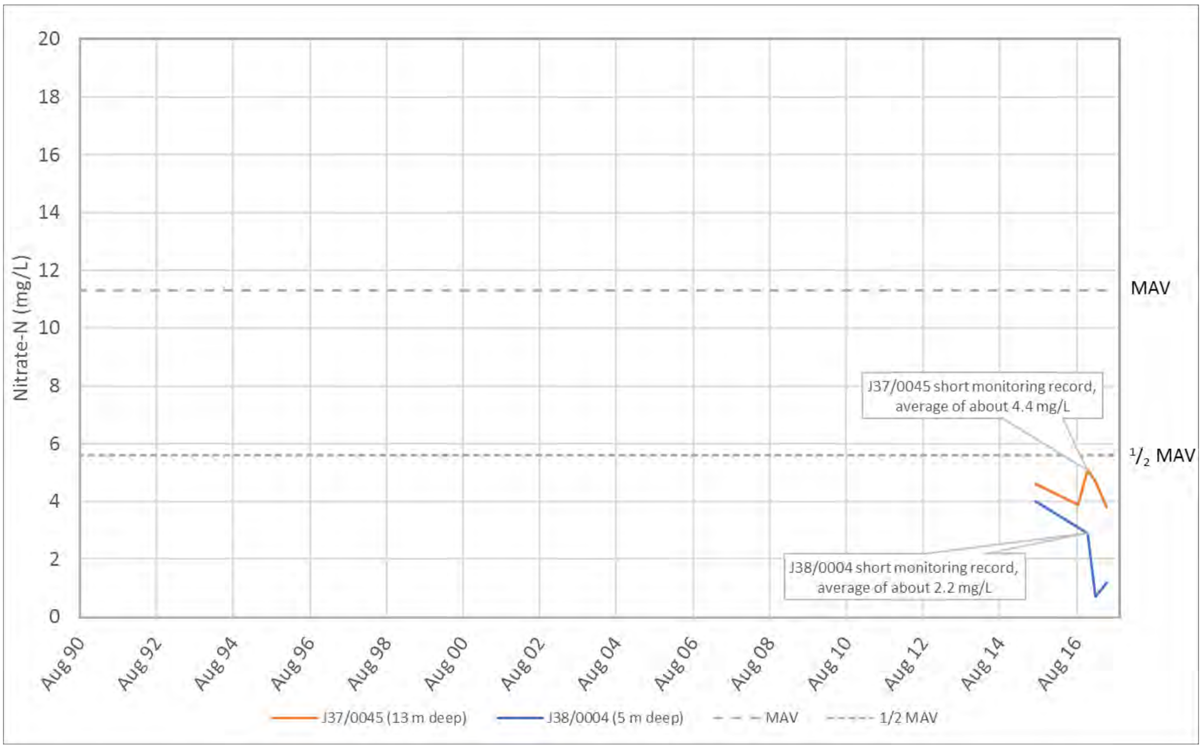

Figure E-5: Nitrate-N trends for long-term monitoring wells in the Geraldine province

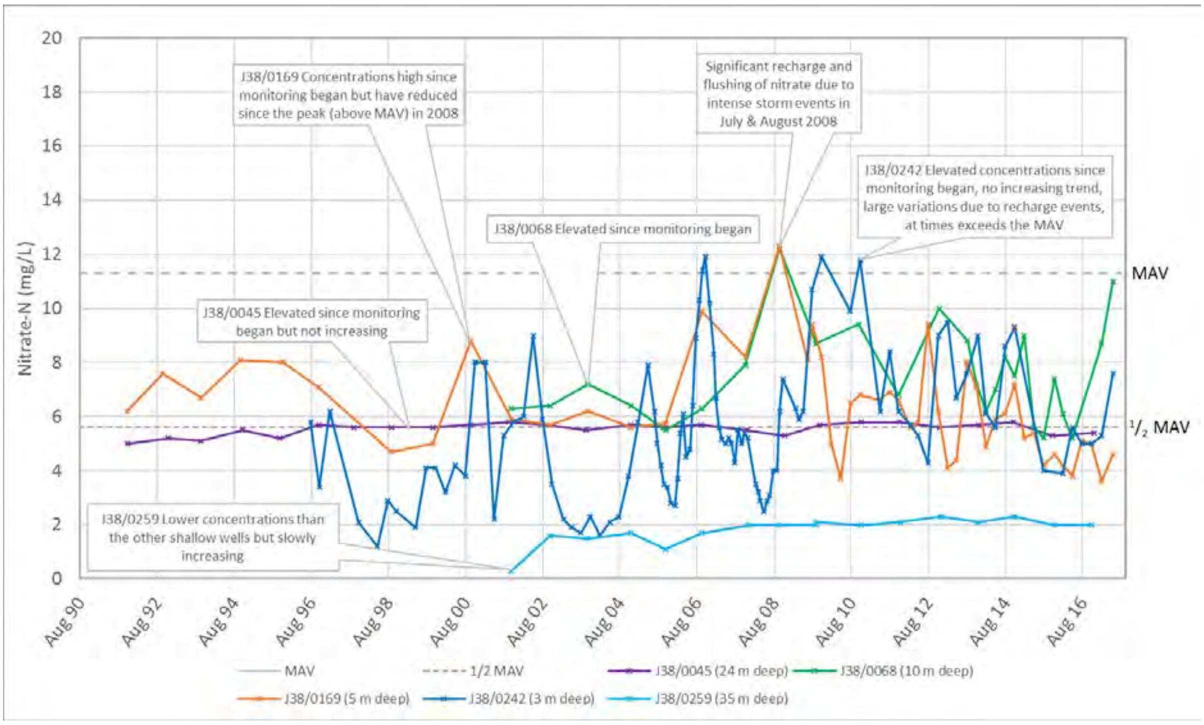

Figure E-6: Nitrate-N trends for long-term monitoring wells in the Opihi province

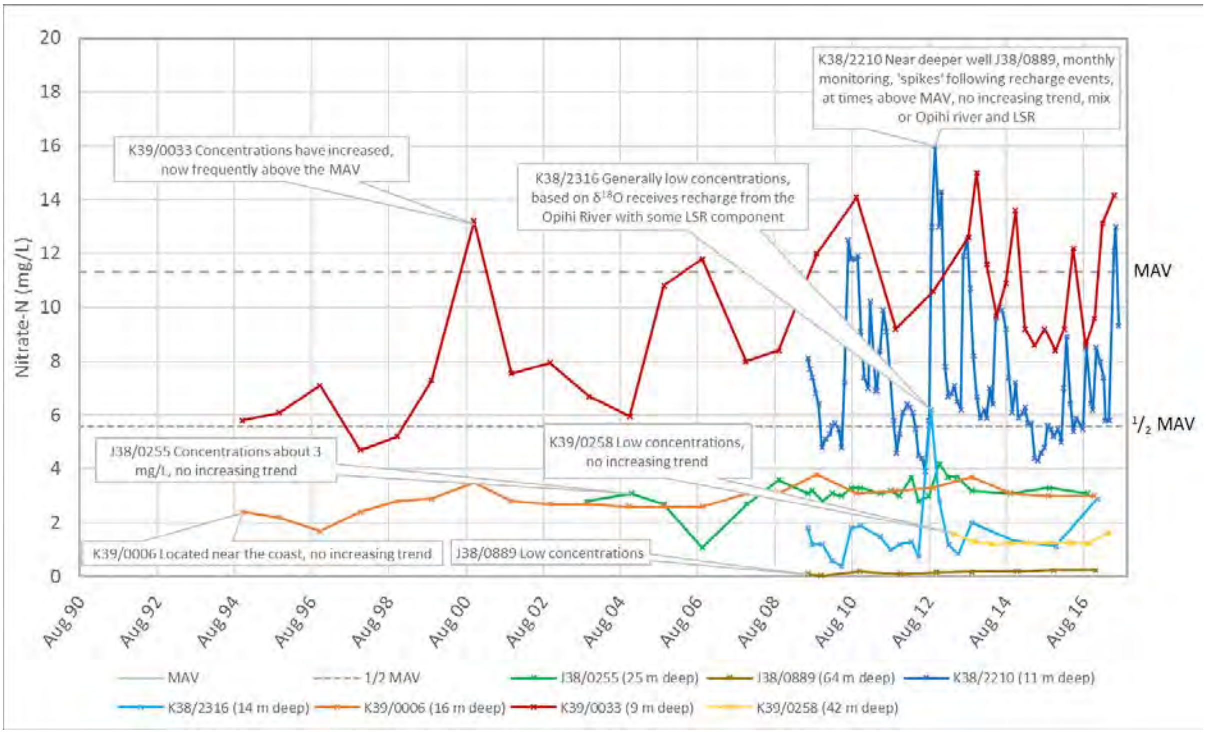

Figure E-7: Nitrate-N trends for long-term monitoring wells in the Opihi province

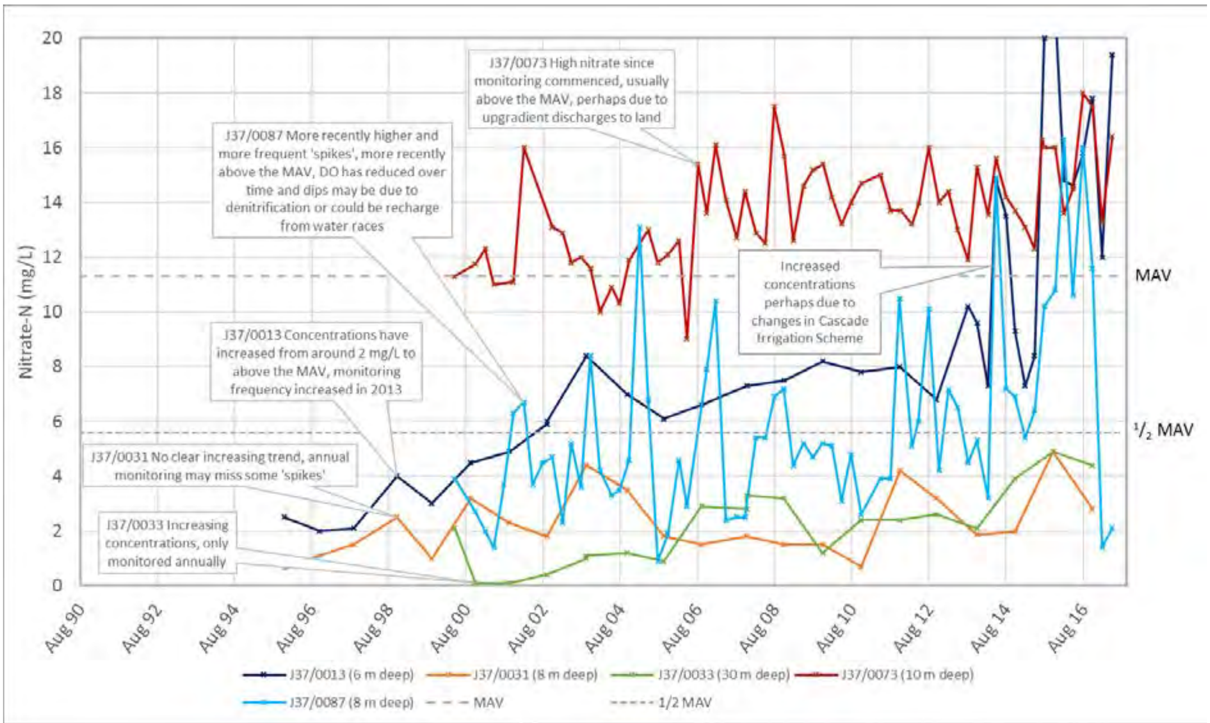

Figure E-8: Nitrate-N trends for long-term monitoring wells in the Ashwick Flat province

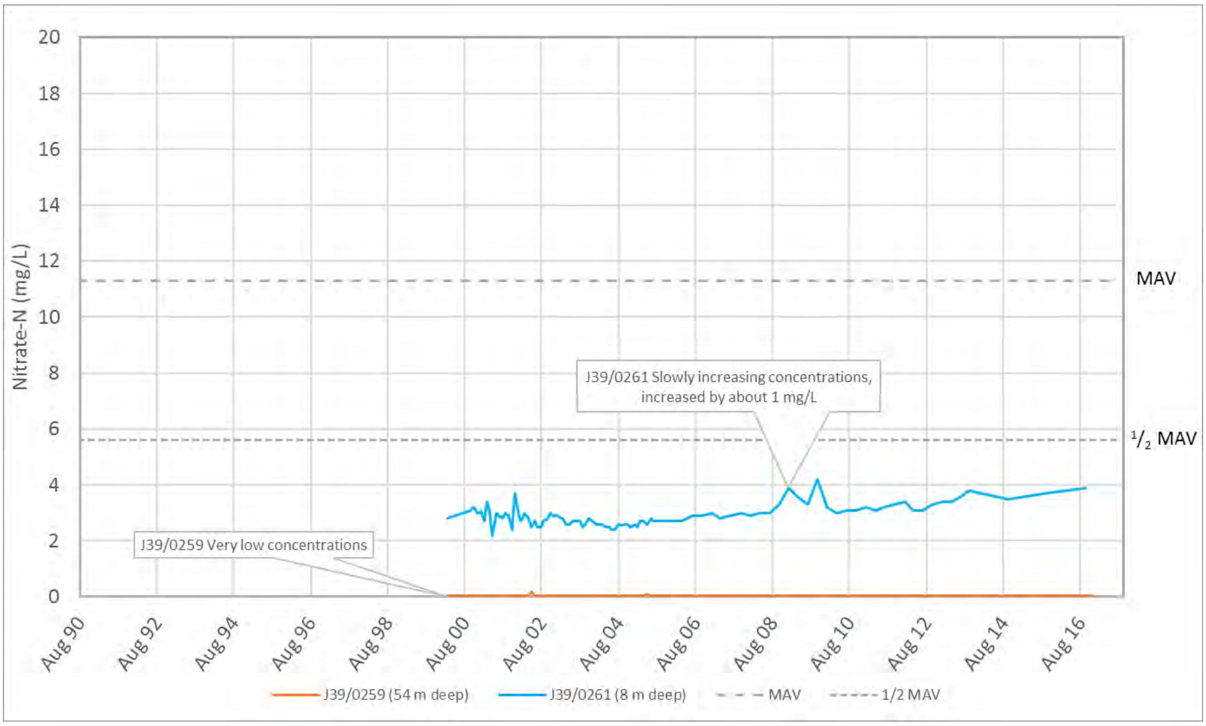

Figure E-9: Nitrate-N trends for long-term monitoring wells in the Timaru province

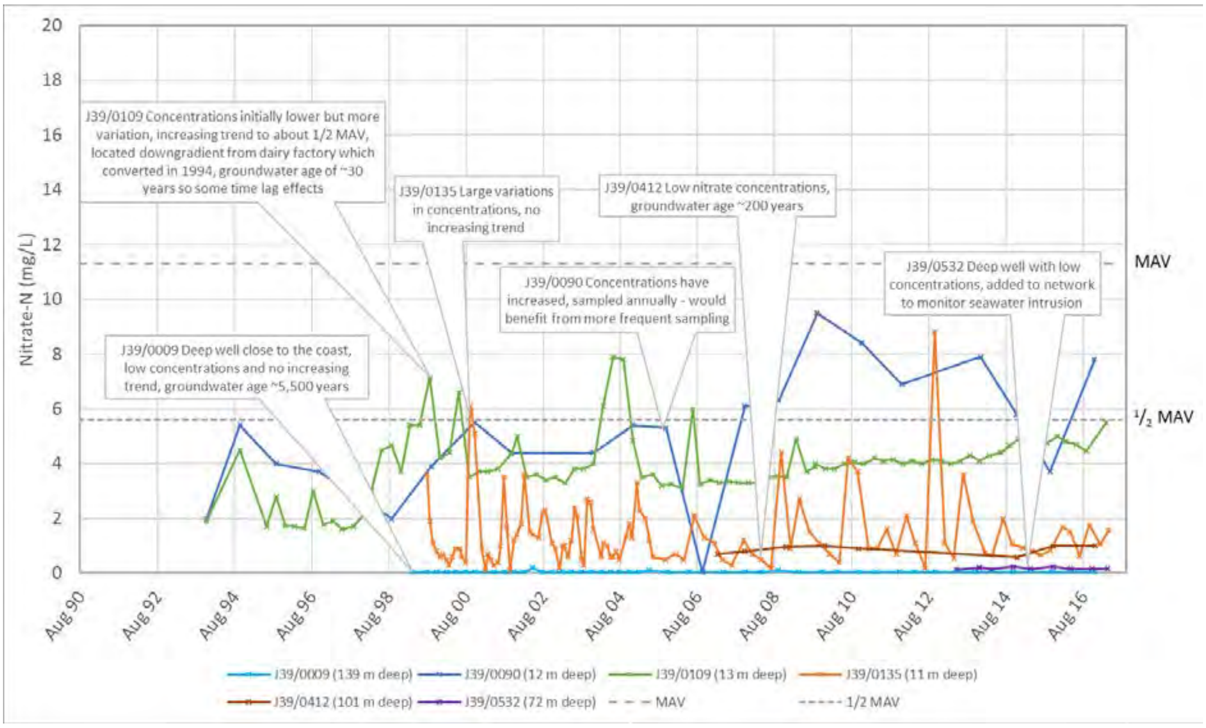

Figure E-10: Nitrate-N trends for long-term monitoring wells in the Pareora province

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